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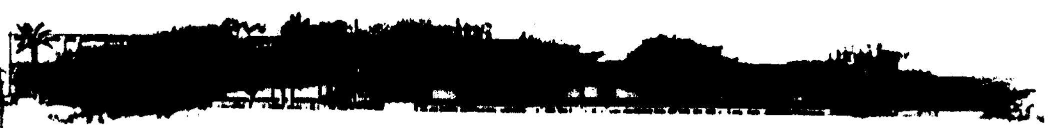

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OPERATIONAL ANALYSIS REPORT
OF THE
MICROWAVE COMMAND GUIDANCE SYSTEM.

PREPARED FOR
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
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FOR
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INTRODUCTION

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SECTION I

INTRODUCTION

This report defines the operational capabilities and status of the ~~Sperry~~ Microwave Command Guidance (MCG) System with respect to its past experiences and its possible future applications in vehicle radar tracking and control*. Accuracy and reliability considerations are included. The technical characteristics of the MCG System and how they are applied to system requirements in the area of missile and drone flight control and recovery are described. Advanced techniques and concepts are described and applied to particular applications such as: service and Q-type drones, Naval missiles and unmanned targets, Army surveillance and reconnaissance, glider and Dyna Soar vehicle recoveries, booster and capsule recoveries, and range instrumentation and tracking concepts as applied to space and orbital vehicles. Advanced data transponder packaging and circuitry information is presented, based on experience gained with the ~~Sperry Data~~ Transponder Set AN/APW-22 (XY-1).

It should be mentioned that the information regarding potential applications, presented herein, represents current thinking which is subject to variations as requirements and concepts vary.

SECTION II

SUMMARY AND CONCLUSION

SECTION II

SUMMARY AND CONCLUSION

The MCG System is capable of controlling unmanned vehicles at high altitudes, in low-level flight, beyond the horizon missions, and in extended range applications. It may also be used for landings and takeoffs of drone vehicles. The system is a versatile, integrated, system that can track a data transponder equipped vehicle, command the vehicle, and receive and utilize a telemetered return from the vehicle. With this capability and versatility, the system lends itself to applications in the drone guidance field, the surveillance field, recovery of orbital vehicles and boosters, and basic instrumentation applications. A particular application may require the use of only a portion of the MCG System while others may require the full system or even extensions of the present system. All of the above applications can be satisfied using the basic MCG concept as a starting reference.

The basic MCG System is presently employed in an application to control QB-47 drones at the Eglin Gulf Test Range (EGTR) in support of Bomarc "B" low level testing. The system when operating in the relay mode configuration, which utilizes the airborne director and ground director simultaneously, with command control emmanating from either station, can position a vehicle in space with a circular probable error (CEP) of approximately 1/2 mile. Through use of an airborne instrumentation system, drone position data can be obtained within the airborne director in a format which is directly compatible with the EGTR data reduction facilities with a CEP of 470 yards.

The current system accuracies were determined as a result of conducting flight tests at the Holloman Air Force Base test facility. The test results indicate that the range equipment has a probable error of 20 yards with a mean bias error of 20 yards rms. The ground director angular tracking system, with all contributing errors minimized, has a probable error in azimuth of 0.45 milliradians and 0.86 milliradians in elevation, with each axis having a bias error of 0.25 milliradians. The airborne director tracking system error is three milliradians in both axes. Drone position plotting accuracies for the ground director and airborne director are 230 yards at the maximum ranges. The latter is dependent upon distance traveled. Plotting of the airborne director position within the airborne director is 1030 yards maximum dependent upon distance traveled. The data handling capability of the system is 3300 bits per second.

System mean-time-before-failures (MTBF) have been generated for an average four hour mission and are listed in Section V. These MTBF's were somewhat lower than anticipated due to developmental problems encountered while evaluating the relay mode of operations. These problems have since been overcome. The MTBF expected for the major elements of the system in terms of reliability are 0.960, 0.948, and 0.967, respectively for the ground director, airborne director, and data transponder which will yield a system reliability of 0.883.

Frequency stability has been shown to remain within the ±2 megacycle specifications requirement. Operationally the airborne director and the drone have been interrogated by the ground director without fail after each element has been independently tested using the MCG special purpose test equipment when based several hundred miles apart.

SECTION III

DESCRIPTION OF SYSTEM

SECTION III

DESCRIPTION OF SYSTEM

The MCG System is a guidance and command system for commanding, tracking, and receiving flight data from high-performance, unmanned vehicles. The MCG System is illustrated in figure 3-1 and shows the elements of the system which are employed in an operational mission configuration. The basic elements of the MCG System include: (1) the Flight Control Central AN/TPW-1, (2) the Command Guidance-Interrogator Set AN/APW-23(XY-1), (3) the Data Transponder Set AN/APW-22(XY-1), and (4) test equipment.

The system provides several major functions to facilitate mission accomplishment: (1) manual and automatic acquisition, and manual and automatic radar tracking and plotting, (2) command control link to the unmanned vehicle (drone), (3) pulse-coded identity link to and from the unmanned vehicle, (4) flight data link from the unmanned vehicle to the Flight Control Central AN/TPW-1, (5) maximum range extension capabilities through the use of a Command Guidance-Interrogator Set AN/APW-23(XY-1) installed in an airborne director, (6) below horizon missions through the use of the airborne director relay mode of operation, and (7) use of a single frequency band with pulse-code modulation. Identity coding, drone commands, return flight data, and radar tracking are provided within a narrow frequency bandwidth.

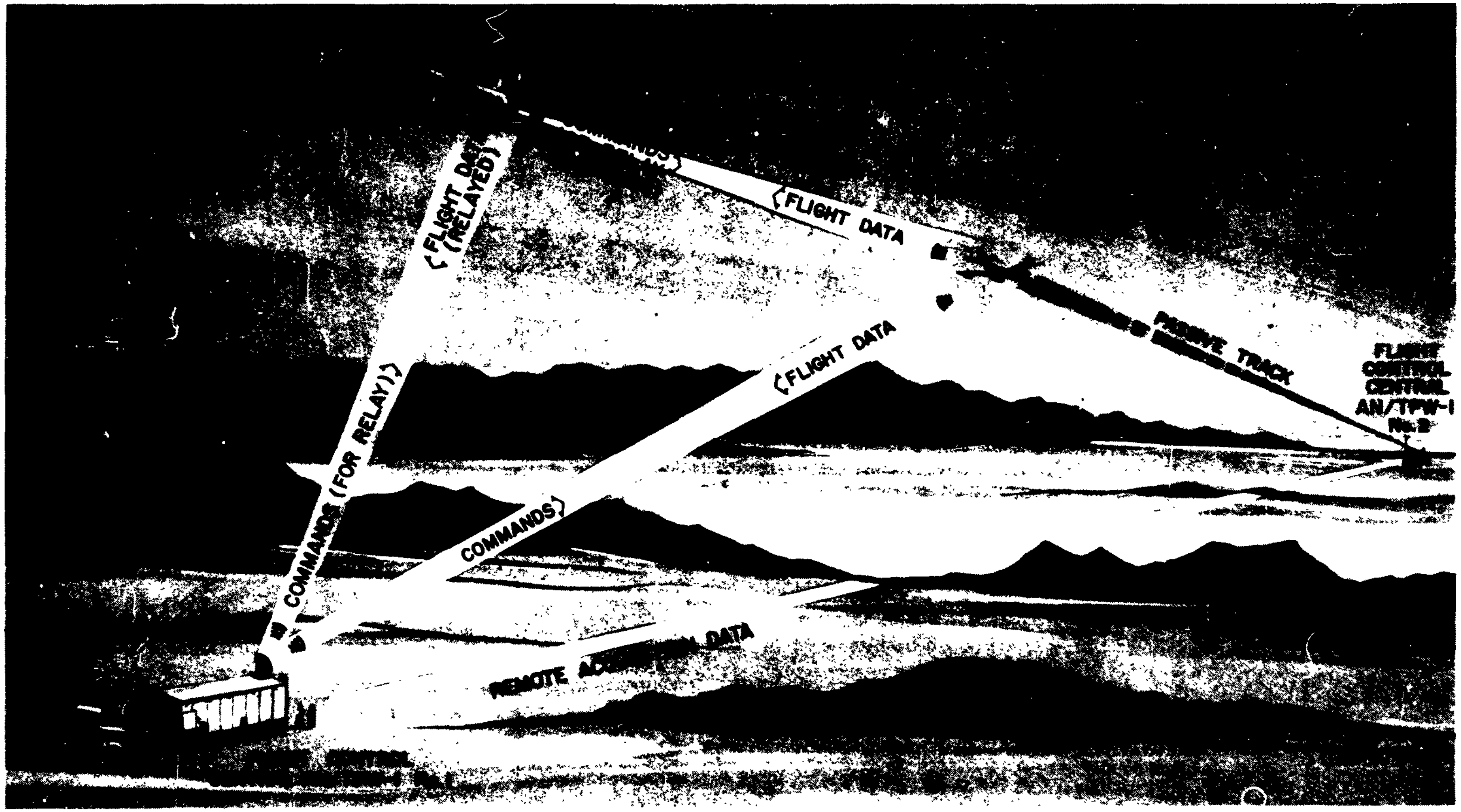

FIGURE 3—1 THE MICROWAVE COMMAND GUIDANCE SYSTEM, OPERATIONAL MISSION

A. FLIGHT CONTROL CENTRAL AN/TPW-1

The Flight Control Central AN/TPW-1 (called ground director) provides the necessary facilities for the control operators to command and control the unmanned vehicle for guidance on a predetermined mission. The ground director facilities are contained within a 30 foot mobile van. Essentially, these facilities are divided into two basic functions: location, identification, and tracking of the unmanned vehicle; and command and control of the vehicle and visual display of command responses. Supporting these basic functions, the ground director provides multichannel UHF communication links between the control operators and essential secondary points such as the airborne director, chase plane, safety pilot*, and base control tower.

Operation of the ground director requires personnel consistent with the mission objectives. For a routine checkout mission, only two operators are necessary: the primary control operator and the radar control operator. For a detailed mission with specific range boundary limitations, an auxiliary operator may assist the primary control operator. All missions can be supplemented by a communication and power operator whose specific duties are to monitor radio and power equipment performance when a mission is in progress. During a routine checkout mission the primary operator assumes the duties of the auxiliary operator. Emergency operation of the ground director can be conducted by the primary control operator and the radar operator.

B. COMMAND GUIDANCE-INTERROGATOR SET AN/APW-23(XY-1)

The second element of the MCG System is the Command Guidance-Interrogator Set AN/APW-23(XY-1) (called airborne director). This equipment essentially duplicates the functions of the ground

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*For common terminology used in drone operations, refer to the Glossary in Section VI.

director from in-flight position. Normal operations of the airborne director are accomplished with three operators: the primary control operator, an auxiliary control operator, and a radar operator. At the discretion of the ground director primary operator, the airborne director can assume complete control of the unmanned vehicle and actually direct the mission, or it may serve as a relay link between the unmanned vehicle and the ground director. In the latter case, the unmanned vehicle is tracked by the airborne director and the airborne director is in turn tracked by the ground director. Contained within the airborne director is transponder equipment which is used for relay mode operation and is similar to the Data Transponder Set AN/APW-22(XY-1) installed in the unmanned vehicle. This relay transponder equipment in the airborne director is used to permit tracking by the ground director and to transmit the flight data from the unmanned vehicle to the ground director.

C. DATA TRANSPONDER SET AN/APW-22(XY-1)

The third element of the MCG System, the Data Transponder Set AN/APW-22(XY-1) (called data transponder), is contained in the unmanned vehicle. The data transponder uses X-band, pulse-coded modulation to effect command guidance, beacon tracking, and flight data reply between the unmanned vehicle and the director stations. The data transponder receives the radar-transmitted coded commands from either the ground director or the airborne director, decodes the commands, and supplies an output command signal to the unmanned vehicle control system. The response to these commands is coded by the data transponder and sent back to the director station in the form of flight data. Included in the reply flight data code is a pulse for the director stations to determine radar range and track.

D. TEST EQUIPMENT

The MCG System includes four specialized test sets which are designed to facilitate functional testing of all three basic system elements. These are the Radar and Data Processing Test Set, the Range and Tracking Test Set, the Drone Simulator Test Set, and the Computer Test Set. The Radar and Data Processing Test Set has been designed to measure the airborne director's and data transponder's power, frequency, sensitivity, data encoding, and data decoding functions. The Range and Tracking Test Set provides a facility for functionally testing the ranging and tracking subsystems of the director stations. The Drone Simulator Test Set provides a simple method for preflight checking of the drone data transponder. The Computer Test Set functionally tests all computing and plotting elements of both the airborne and ground director. All MCG equipment is normally used during operational checkout of the system.

E. GROUND DIRECTOR - SIMPLIFIED THEORY

In order to have a better understanding of the system capabilities, a discussion of the simplified theory of operation of each of the major elements of the system is provided. The description of the simplified theory of operation for the ground director station is divided into three functional subsystems and associated support equipment as shown in figure 3-2. These subsystems are the tracking, the guidance, and the computing subsystems.

1. Tracking Subsystem

Figure 3-2 illustrates that the transmitting and receiving (interrogation) function is coupled with the range computing and radar indicating components to form the tracking subsystem. The basic mission of this subsystem is the identification, acquisition, and tracking of the unmanned vehicle.

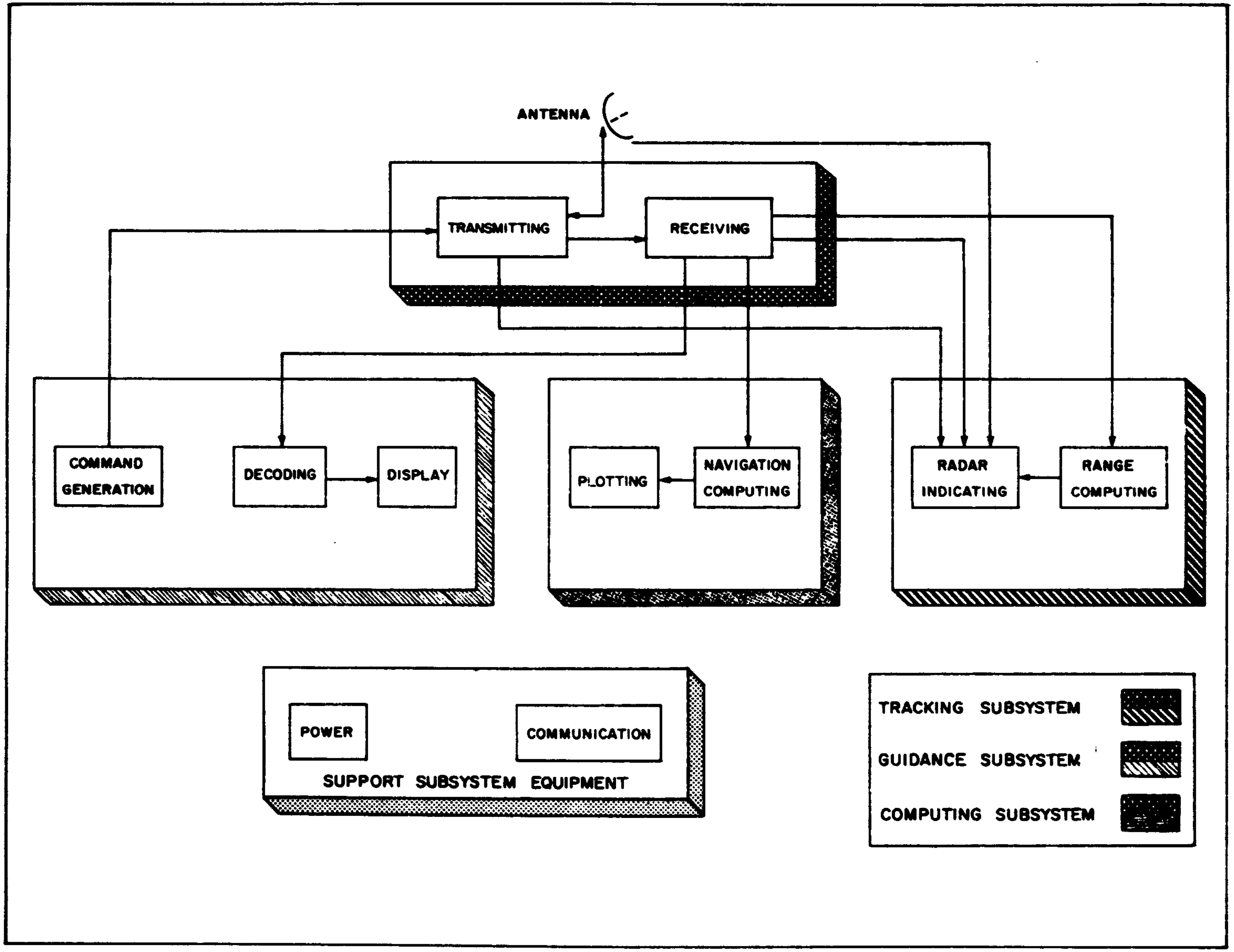

FIGURE 3-2 SIMPLIFIED BLOCK DIAGRAM, FLIGHT CONTROL CENTRAL AN/TPW-1

Identification is accomplished by means of transmitting a properly coded series of pulses which commands a particular data transponder to respond to this transmitted message. Inputs to the data transponder that are received as a result of this transmitted message, if properly coded, answer the interrogation from the ground director. This response, in turn, contains a previously selected identity coding so that improperly transmitted identity codes from the data transponder will not be detected by the ground director. Therefore, no resulting action will take place. If the codes are properly aligned in both the ground director transmission and the data transponder transmission to the ground director, the identification function has been satisfied.

Initial radar acquisition of the unmanned vehicle is accomplished manually, or if the target area is known, through the use of the sector scan mode of search. When acquisition is made, a target indication appears on the acquisition equipment within the ground director van. The radar antenna may then be "locked on" and automatic tracking may be utilized. As the operator desires, the target now may be either automatically or manually ranged and bracketed by the acquisition gate within the range equipment. When this is accomplished, the unmanned vehicle is acquired in both angle and range, and positive plotting and position control is established.

Continuous angle tracking is made possible by the use of error signals generated by the nutation of the radar antenna. These error signals are used to control the antenna servo system in azimuth and elevation. Range tracking is accomplished by servoing a generated range mark to be in time coincidence with the reply received from the data transponder in the unmanned vehicle. Appropriate radar range readout dials on the range equipment, which are mechanically coupled to the servo function, present a decimal number display of the radar range to the

target and provide necessary range information for the computing and plotting equipment. During this tracking function, continuous display of the vehicle position is available to the radar operator and the primary control operator.

2. Guidance Subsystem

The guidance subsystem consists of the interrogation function plus command generation, decoding, and display as shown on figure 3-2. The basic mission of this subsystem is the guidance of the unmanned vehicle plus a visual display of the on-off data commands and the readout of returned flight data parameters. The generated command pulses pertinent to the guidance subsystem are transmitted to the vehicle in a series. Thirty-one or sixty-two possible command combinations exist for command functional allocation depending upon equipments used. These commands control the unmanned vehicle in flight and, therefore, supply the guidance requirement.

The transmitted reply from the data transponder in the unmanned vehicle consists of six proportional channels of flight data and 16 on-off functional readouts. These readouts indicate the presence or absence of the on-off function as it occurred in the vehicle. These data frames are decoded in the ground director equipment, and the results are displayed at the primary operator's console. Parameters of flight appear on normal instrument-type indicators. On-off functions appear as illuminated indications.

3. Computing Subsystem

The computing subsystem consists of the interrogation function plus navigation computing and plotting. The basic mission of this subsystem is to compute and display a continuous track of the position of the unmanned vehicle. The track is displayed in X-Y coordinates relative to true north. The computing function is performed by obtaining antenna position

readouts and combining them with range data obtained from the guidance equipment. Then, by an appropriate computation, the results in an X-Y position output are applied to the plotting board. Thus, the position of the unmanned vehicle is displayed with respect to the position of the ground director. This X-Y information appears on the plotting board as a continuous track of the position of the unmanned vehicle from the known X-Y reference starting point, which is the ground director. The X-Y coordinates may be rotated so that the plotting board grids will represent a true display of the actual position of the unmanned vehicle with respect to true north.

4. Support Equipment

Support for the functional capabilities of the three basic subsystems is provided in the ground director through its power systems (primary and secondary) and its UHF communications equipment. The primary power to the ground director may be supplied by commercial or base power mains or by two diesel driven generators, each having a nominal output capability of 30 kw. The UHF communication capabilities include a single channel transmitter-receiver and a 10-channel transmitter-receiver, either or both of which are used for voice communication between the ground director and other manned elements involved in the accomplishment of any given mission. Facilities are provided within the ground director for remote channel selection and control of the communications equipment and for recording all voice communications during a mission.

F. AIRBORNE DIRECTOR - SIMPLIFIED THEORY

The command guidance-interrogator set in the airborne director is divided into the same three functional subsystems and associated support equipment as the ground director. The relationship between these subsystems is shown in the simplified block diagram, figure 3-3. These subsystems consist of the

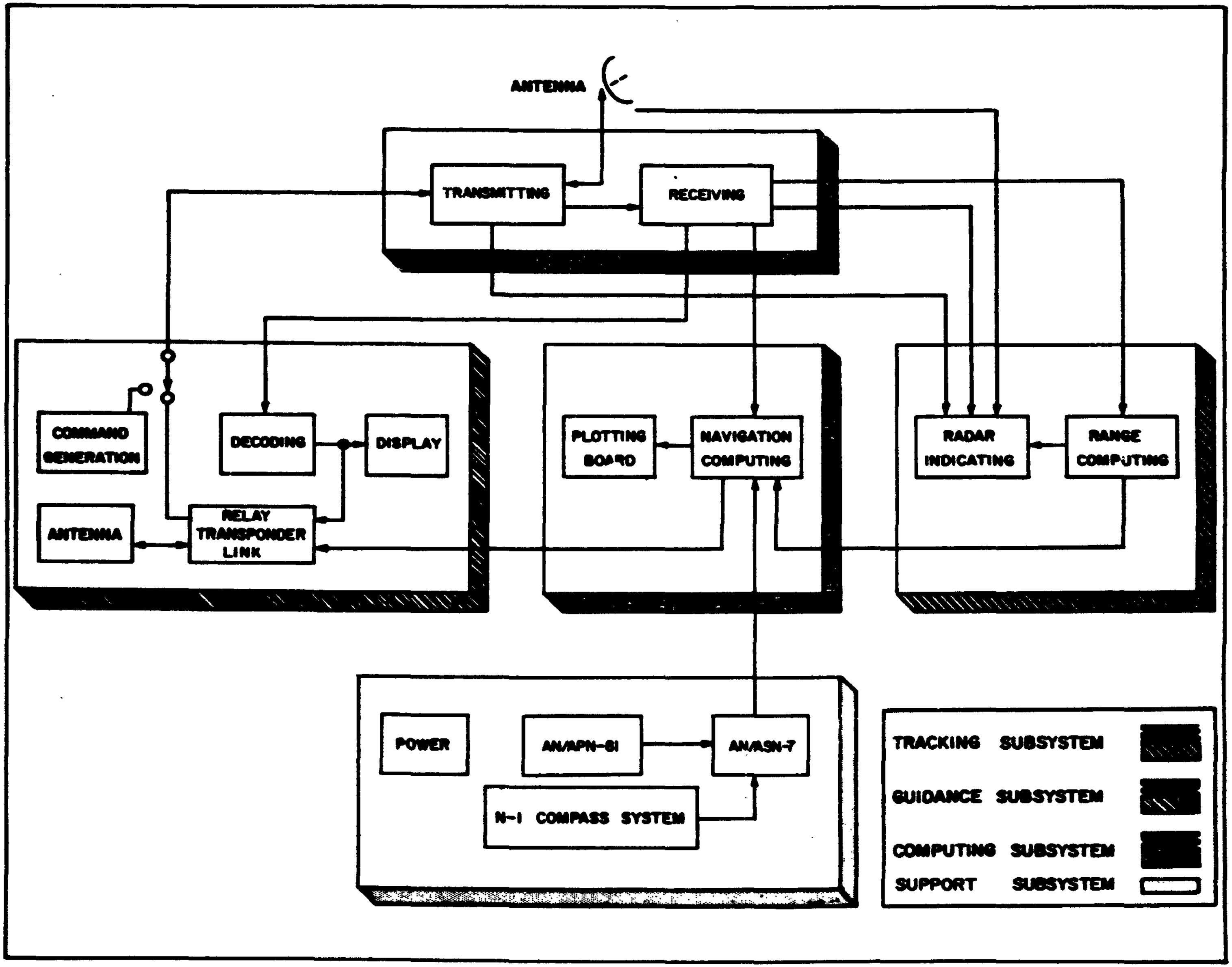

FIGURE 3—3 SIMPLIFIED BLOCK DIAGRAM, COMMAND GUIDANCE-INTERROGATOR SET AN/APW—23(XY—1)

tracking, guidance, and computing systems, with the necessary supporting functions provided by system power supplies and external equipment.

The tracking subsystem and the guidance subsystem of the airborne director are virtually identical to those described in the ground director. The major difference between these two elements is contained within the computing subsystem equipments.

The computing subsystem consists of the interrogation function plus navigating, computing, and plotting. The basic mission of these subsystems is to compute and display a continuous track of the position of the unmanned vehicle and the airborne director with respect to a fixed reference position. This track is displayed in X-Y coordinates relative to true north.

The navigation computing components receive latitude and longitude information from an external Radar Set AN/APN-99, which consists of a Doppler Set AN/APN-81 and a Navigational Computer Set AN/ASN-7, which computes the airborne director position. Unmanned vehicle position data, relative to the airborne director, is computed from a drone bearing and range relative to the airborne director. This is summed with airborne director position to give drone position with respect to a fixed ground reference point when referenced to true north. An elevation resolver and an azimuth resolver are physically located on the radar antenna. The output of the elevation resolver is a reference voltage times the cosine of the antenna elevation angle. This signal is combined with aircraft pitch and roll information to give a true elevation angle. A slant range signal from the range equipment is combined with the true elevation angle to give ground range to the drone. The ground range signal is combined with antenna azimuth information to give X-Y position of the drone with respect to the

airborne director. The drone X-Y position is summed with the airborne director X-Y position to give the drone X-Y position with respect to the fixed reference coordinates. This X-Y drone information appears on the plotting board as a continuous track of the position of the unmanned vehicle.

The airborne director X-Y data also appears on the plotting board and provides a continuous track of the airborne director position. As in the case of the ground director, the coordinates may be rotated in order to position the plotting board grid with respect to a true display of the actual position of the unmanned vehicle.

G. DATA TRANSPONDER - SIMPLIFIED THEORY

The Data Transponder Set AN/APW-22(XY-1) is the element contained in the unmanned vehicle. It is designed for operation in a nonpressurized environment from sea level to 70,000 feet. It is capable of decoding 31 on-off commands (a modified version will decode 62 on-off commands). Eight channels of flight data are encoded for transmittal to either the airborne director or the ground director station. Six proportional channels of data provide proportional flight information. The remaining two channels are used to transmit 16 bits of on-off flight data information.

Briefly, the data transponder operates as follows: R-F command code pulses are received by a receiver-transmitter unit, are detected and mixed with a local oscillator signal by a superheterodyne receiver, are amplified by an amplifier detector, and are decoded in a coder-decoder for application in a relay assembly. In turn, the relay assemblies distribute the commands that control the drone. Flight data from the drone transducers are applied to a signal data converter for digitizing and coding in a coder-decoder. Video digital pulse codes are used to modulate the magnetron transmitter for R-F transmission to the ground

or airborne director station. The data transponder has application in either manned or unmanned drone aircraft and, to date, has been used in a QF-80, a QB-47, the XQ-2C, and the XQ-4B vehicles.

SECTION IV

SYSTEM CAPABILITIES

SECTION IV

SYSTEM CAPABILITIES

A. OPERATIONAL MODES

The following modes of operation can be accomplished with the MCG System:

- Direct control by the ground director
- Direct control by the airborne director
- Relay control by the ground director through the airborne director
- Chain station operation through two or more ground directors.

Under direct control by the ground director, the system has a basic range capability of 200 nautical miles. In this mode of operation, the unmanned vehicle must at all times be above the radar horizon. Flight data and command data are directly exchanged between the ground director and the data transponder in the unmanned vehicle. The position of the unmanned vehicle is displayed on the ground director plotting board in X-Y coordinates derived from radar tracking information obtained from the interrogation radar and computer in the ground director. Upon a verbal command from the primary control operator in the ground director, the airborne director can assume full command of the unmanned vehicle. In this case, identical control features are exercised by the airborne director and full flight information and position of the airborne director is relayed to the ground director. The positions of the unmanned vehicle

and the airborne director are plotted on the ground director and airborne director plotting boards.

The relay mode extends the control range of the ground director to approximately 400 nautical miles through use of the relay capability in the airborne director. Operation of the unmanned vehicle below the radar horizon is now possible since the airborne director can control the unmanned vehicle at elevation angles below the horizon as long as the ground director is within radar line-of-signt of the airborne director. Over-the-horizon control is presently being exercised at the Eglin Gulf Test Range (EGTR). The airborne director receives position and flight data from the unmanned vehicle and stores it in the relay transponder equipment. The ground director then interrogates the airborne director, thus deriving the position of the airborne director plus the stored flight data from the unmanned vehicle. The ground director is now capable of displaying flight data information plus the position of the unmanned vehicle and the airborne director. Commands from the ground director are relayed to the unmanned vehicle by the airborne director.

In addition to the direct control and range extension capabilities, other provisions of flexibility exist in the MCG System. Two or more ground directors may be connected through appropriate communications and data transmission links such as microwave and land line. In this series mode of operation, radar position information, commands, and flight data can be transmitted from one ground director to another so that the unmanned vehicle may be passed down range without loss of control capabilities.

The direct control mode of operation is not restricted to airborne operation. The ground station is capable of conducting both landing and takeoff as well. During a QF-80 landing test program conducted at the Sperry test facility at MacArthur Field

in the summer of 1959, the ground director tracked and controlled the drone throughout the entire landing procedure, which included the initial approach, final approach, flareout, and runway roll-out. It was also shown that the position computing and plotting capability was such that an operator can satisfactorily guide a drone into an initial approach funnel and from that point "beep" operators stationed along the runway can flare the drone and control it during runway rollout until standstill. Utilization of the external beep operator, who uses the "eyeball" technique, readily compensates for any ranging errors present in the system. Results of the test showed that a 30-foot bias error existed in the system within the ground station. This error has been known to exist for some time but can be quickly compensated for when a particular application deems it necessary. Sperry report LA-3272-0105, entitled "Microwave Command Guidance Adaptation to Service Drones", dated November 1959, is a detailed report on the landing capabilities of the prototype ground director. Specific commands are required for landing a particular aircraft. Forty-three on-off commands are required for complete QB-47 operations at EGTR. A modified six-bit transponder would provide a 62-command capability by allowing 19 to be used as multiple commands. A terminal area control mode (TAC) is easily incorporated to switch out commands used for the down range functions to provide for the landing and take-off phase of a mission. A suggested list of commands necessary to remotely fly and land a QB-47 is given in table 4-1. Because the QF-80 is much less complex than the QB-47, the QF-80 requires only half of the number listed in table 4-1.

B. OPERATIONAL CAPABILITIES

Succeeding paragraphs define the operational capabilities of the MCG System. Included is a discussion of the range capability, the angle tracking capability, data handling and plotting capability, and the acquisition capability of the system.

TABLE 4-1

SUGGESTED QB-47 TAKEOFF, LANDING, AND IN-FLIGHT COMMAND ALLOCATIONS

Individual Commands	Individual Commands
1. Up	18. Altitude Select
2. Down	19. Flight Data Blank
3. Right	20. ILS Arm
4. Left	21. ILS Off
5. A/S Pitch On	22. R/S Arm
6. A/S Throttle On	23. Explode
7. A/S Throttle Off	24. Skid On
8. ACE On	25. Skid Off
9. Direct Pitch	26. Gear Up
10. Cruise A/S On	27. Gear Down/Brake Chute
11. Cruise A/S Off	28. Wing Flaps Up
12. Circle Turn	29. Wing Flaps Down/Chute Jet
13. Nav Turn	30. Latch Brakes
14. Throttle Intlk. On/Off	31. Unlatch Brakes/App Chute
15. INC	32. Brakes
16. DEC	33. ATO Arm
17. Antenna Select	34. TAC On/Off

35. Camera Arm/Disarm* - Up-INC-Left
36. Camera On* - Up-INC-Right
37. EFEI On* - Up-DEC-Left
38. Engine Select* - Up-DEC-Right
39. Engine Shutdown* - Down-INC-Left
40. IRCM Select (fuel)* - Down-INC-Right
41. IRCM Actuate (IR and chaff)* - Down-DEC-Left
42. ECM Select* - Down-DEC-Right
43. ECM Actuate* - Brake Chute-Left

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*Commands which are switched when TAC mode is ON.

TABLE 4-1 (cont)

Multiple Commands	Multiple Commands
44. DEC - Left	54. Brakes Latch - Left
45. DEC - Right	55. Brakes Latch - Right
46. INC - Left	56. Up - INC
47. INC - Right	57. Up - DEC
48. Up - Left	58. Down - INC
49. Up - Right	59. Down - DEC
50. Down - Left	60. Brake Chute - Right
51. Down - Right	61. Chute Jet - Left
52. Brakes - Left	62. Chute Jet - Right
53. Brakes - Right	

1. Range

The range capabilities of the MCG System, as well as any other radar type of equipment, are dependent upon the number of intricately related parameters. Such parameters as frequency, atmospheric loss, antenna size, polarization, nutation, receiver noise figure, integration, and bandwidth are usually taken into consideration. The MCG frequency was specifically selected to minimize atmospheric attenuations that are significant at long ranges and high frequencies. As a result, frequencies in the X-band region were selected. Antenna size was selected to be consistent with radar ranging requirements and logistics aspects. An original antenna design was modified and adapted to the ground director. An antenna for the airborne director was specifically designed to have characteristics that were basically similar to this antenna configuration. This antenna has a somewhat lower gain than the ground director antenna by virtue of its size (24-inch dish) which was dictated by the allotted space for a parabolic reflector inside the airborne director radome.

Regarding polarization of the system, both antennas of the MCG director stations were chosen to have circular polarization while the drone was chosen to have linear polarization like that of the XQ-2C and the XQ-4B. Circular polarization was selected to minimize reductions in system sensitivity that are normally present when two linear systems are used on an aircraft that maneuvers to angles in excess of 45 degrees. The reduction in sensitivity is apparent and is in accordance with a cosine squared function. A 3 db loss will result when a circularly polarized system is used with a linearly polarized system. This loss was accepted in order to obtain a constant signal strength regardless of antenna orientations of either the director station or the unmanned drone vehicle.

The tracking systems in both the ground director and airborne director utilize a nutation type of tracking detection. It is used because of its simplicity when compared to monopulse or base-time systems. Receiver noise figures were based upon desired range calculations and sensitivities that were required and readily obtainable. Receiver bandwidths were determined by frequency stability considerations of various microwave components and by favorable signal-to-noise ratios. The bandwidths were made wide enough to receive the detected pulses, thereby maximizing the over-all video signal-to-noise ratio.

Based on these discussions and on considerations of system parameters, the range capabilities of the system were computed. These calculations were based upon the return link from the data transponder to the director station since the transmitted power output capability of the data transponder is one-fifth that available in the director station. Results of this investigation, which also included losses due to waveguide components, concluded that a range capability of 218 nautical miles was possible. During actual operations that took place at Phoenix, Arizona, at Holloman Air Force Base, and at Eglin

Air Force Base, angle tracking ranges to 230 nautical miles have been obtained. Range tracking is limited in that the physical limit stops of the range computing equipment are currently set to the 218-mile limit.

Actual tests were conducted on the equipment at Holloman Air Force Base to determine the over-all range accuracy of the system. The results obtained indicate a probable range error of 20 yards with a mean bias error of approximately 20 yards. These findings were the results of a statistical review conducted on the data obtained. Range accuracies for the airborne director are the same since identical equipments are used. As previously stated, ranges beyond 200 nautical miles can be obtained with 400 miles possible in the relay configuration. Figure 4-1 shows the extended range coverage of the system for particular drone altitudes when the system is used in the relay configuration.

2. Angle Tracking

The primary function of the angle tracking servo system is to supply the mechanical power and control required to move the antenna in elevation and azimuth so that it will point at a target. The servo system has several modes of operation. The primary mode is the angle track mode in which the angle servos receive the input signals from the radar receiver. In addition, there are positional and rate hand controls, circle scan, sector scan, and remote acquisition modes. Choice of these modes is controlled at the radar console.

The antenna for the ground director is located on top of the mobile van. It is free to rotate 360 degrees in azimuth and from approximately -5 to +88 degrees in elevation. The antenna has a nominal 2.7-degree beamwidth at the 3 db crossover point. The antenna is capable of tracking up to 15 degrees per second in azimuth and to 12 degrees per second in elevation. Tracking rates available in the airborne director antenna system are approximately equal to those of the ground director

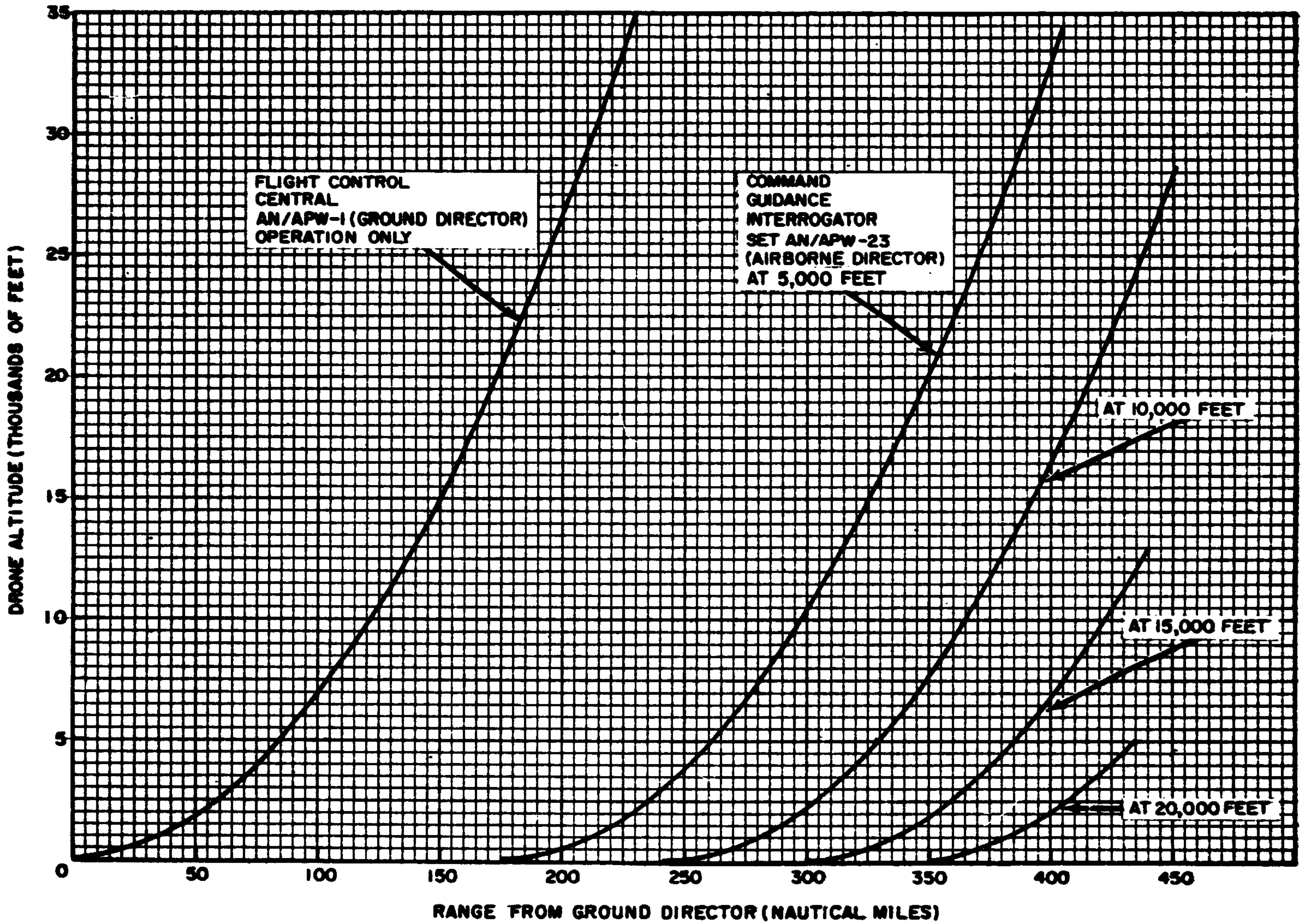


FIGURE 4-1 MINIMUM DRONE ALTITUDE VERSUS MAXIMUM RANGE FROM FLIGHT CONTROL CENTRAL AN/TPW-1 (GROUND DIRECTOR)

system. Tracking accuracies of the ground director were obtained in conjunction with the tests performed while obtaining range accuracy data at the Holloman Air Force Base, New Mexico. The results obtained from a statistical evaluation indicate that, through proper calibration and removal of possible existing bias errors, a probable error in azimuth angle determination is 0.45 milliradian with a 0.25 milliradian bias error. Also, a probable error in elevation angle determination was determined as 0.86 milliradian with a 0.25 milliradian bias error. The difference between the azimuth and elevation determination capability is considered to be largely due to antenna beam interference with the ground which results in a higher received noise level input.

Probable error is defined as 0.675 times the standard deviation, and 50 percent of the total errors have absolute magnitudes greater than the probable error. The standard deviation of a set of observations is the root-mean-square value of the deviations from the mean bias error. The mean bias error is the value represented by the amount the center of the random data is offset from the target location. The over-all results indicate that the circular probable error in position determination for the ground director is 1.37 yards per nautical mile.

Tracking accuracies possible with the airborne director antenna system are slightly better than 3 milliradians. The variation in accuracy compared to the ground director is largely due to the fact that the basic platform is continuously moving and vibrating and seldom maintains a steady-state reference which is the case for the ground director. The tracking antenna for the airborne element of the system is presently installed in the nose of a GC-130 aircraft. There are some angular coverage limitations resulting from such an installation similar to that which would occur for any other location. Looking directly forward, the antenna has an upward elevation coverage capability

of approximately 20 degrees. Laterally, the antenna has an upward (above the horizontal) elevation angular coverage of 30 degrees. The antenna is free to move 360 degrees in azimuth; however, looking aft, it is possible to obtain coverage from 12 degrees below the horizontal to 85 degrees above the horizontal which is the angular elevation limit of the antenna.

For the most part, operations with the airborne director will be at extended ranges requiring only small antenna angular deviations from the horizontal plane. In the case of operations with Q-type drones, which are launched directly from the airborne director, the tracking antenna will be initially directed toward the unmanned vehicle mounted on a pylon of the launch aircraft. The antenna will track the unmanned vehicle from launch to the maximum extended range of the system. During the initial launch phase, however, angular lags of 2 to 2.5 degrees are to be expected in both the azimuth and elevation axes, until such time as the unmanned vehicle is sufficiently far ahead of the launch aircraft to reduce the rate of track. Figure 4-2 shows the upward coverage capability of the tracking antenna when the drone vehicle is at specified relative altitudes. All positions below these altitudes are readily trackable.

3. Data Handling

In their present configuration the ground director and airborne director can transmit 31 commands. A second version of this equipment has a 62-command capability. Representative command allocations for a QB-47 are listed in Section IV under Mission Capabilities. Command outputs of the system, mentioned in the simplified theory of operation, are generated within each of the director stations from a command control panel containing various switches available for the operator to control the vehicle. Actuation of any of these switches will result in a particular command transmission to the data transponder of the unmanned vehicle and will eventually result in a controlled

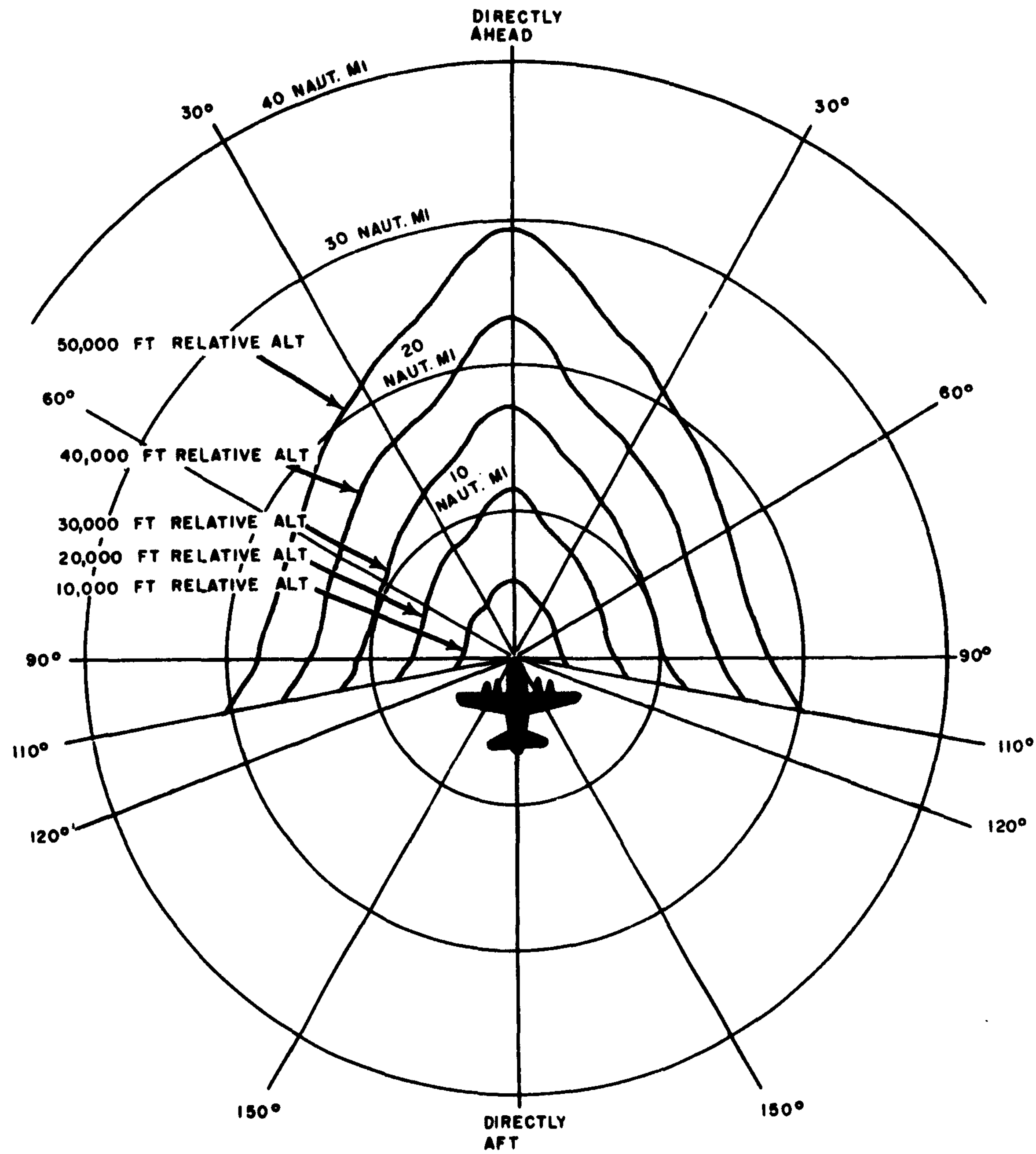


FIGURE 4-2 ANTENNA COVERAGE VERSUS AIRCRAFT-DRONE RELATIVE ALTITUDES, DRONE ABOVE DIRECTOR AIRCRAFT

action within the vehicle. Flight data display panels are contained within each of the stations for readout of six proportional channels of data and various on-off functions. The displayed proportional type data is usually of a type such as heading, airspeed, Mach number, altitude, engine rpm, bank angle, and pitch angle. Accuracy of the data readouts obtained from actual flight test is one-half of one percent. (Refer to Sperry Report LA-3272-0105, entitled "Microwave Command Guidance Adaptation to Service Drones", dated November 1959.) Any type of proportional channel output can be readily adapted to this system.

4. Plotting

The position readouts of both the unmanned vehicle and the airborne director station are presented on a 30 x 30 inch plotting board in the ground director. This represents an approximate range scale of 400 miles by 400 miles. Standard Lambert Conformal Maps with scales of 100,000:1, 250,000:1, 500,000:1, and 1,000,000:1 are readily available for use in both the ground director and airborne director stations. The systems are specially equipped with parallel scale factor switches to allow the drone plotting scale to be expanded remotely. The expansion is usually accomplished at a point on the plotting board which will not interfere with the mission underway. The plotting board is situated immediately in front of the primary operator's console and is used as a continual reference of vehicle position throughout the mission. Actual plotting results obtained to date indicate that with the system properly calibrated, a circular probable error in the ground director of approximately 130 yards can be obtained at a range of 100 nautical miles. Flight test results within the airborne director indicate that the system will plot the position of the unmanned vehicle to within 600 yards (not including the error of the AN/APN-99 Doppler Radar Set). Position plotting of the unmanned vehicle, as plotted within the airborne director, is possible to within

1670 yards maximum after all previous system errors are eliminated. The most significant errors are accumulated within the AN/APN-99 Doppler Radar Set (1 percent of distance traveled) and within the N-1 compass system (1/4 to 1/2 degree).

5. Acquisition

Acquisition of the transponder-equipped unmanned vehicle can be accomplished with the MCG System. If the general location of the target is unknown, the antenna can be placed in the search mode. The antenna will then rotate clockwise in azimuth at approximately 6 rpm. The elevation angle of the antenna is manually controlled throughout the entire search phase. Acquisition of the target using MCG is much simplified when compared to skin track or beacon tracking radars. These latter systems require that objects to be tracked be acquired in angle, in range, and, oftentimes, in frequency before positional contact and control is established. With MCG it is necessary to manually acquire tracking in angle only. Range acquisition is automatic immediately upon detecting a target. A manual override is provided to assist in a more rapid range acquisition. Frequencies are fixed and require no adjustment.

When a target return is observed on the plan position indicator at the radar operation station, the operator positions the antenna to this fix. If no target is observed while sweeping the antenna in azimuth, the elevation control should be adjusted up or down, depending on the drone's expected altitude relative to the director station. The operator continues sweeping in azimuth while adjusting elevation until a target return is observed on the plan position indicator. When a target appears, the operator selects the manual mode. He then immediately adjusts the antenna azimuth and elevation position to obtain the best response from the target. Correlation of this response can be observed on the R-scope at the radar operator's location. When a TARGET DETECT indication appears on a light

indicator located at the radar station, the operator switches the antenna controls to the track mode. The antenna will then track the target automatically. If the range gate for the system has been adjusted to be at the maximum range and if the target is at the maximum range, the operator may allow the range equipment to acquire automatically, or he can manually slew the range gate to lock-on the target. The same condition applies if the acquisition gate of the range equipment is at a close-in position. The operator may choose to manually control the range gate to lock-on the target, or may choose to do it automatically. When the RANGE TRACK light is illuminated, indicating that range lock-on has been accomplished, the primary controller can assume his command control duties. This procedure is much simplified if the general target direction is known. Once the area is known, sector scanning in azimuth at widths up to approximately 60 degrees may be selected. Then the operator need only adjust the scanner in elevation until a target reply is received. During this sectoring mode of search, the antenna oscillates sinusoidally about the initial manual antenna reference position established by the radar operator. The width and rate of the sectoring are controlled by two independent controls. Once a target position is determined the automatic track mode is established. Adjustment of the range gate at this time is similar to that previously described for the search-type operation.

In most drone-type operations, the approximate target azimuth is known. Under these conditions, acquisition times are usually small. Actual acquisition times as short as two seconds are possible if the position of the vehicle is known to within 20 degrees. Both major director elements of the system, the ground director and the airborne director, acquire and control a target using virtually identical equipment; therefore, operational familiarity with either director station will permit an individual to operate from either station.

C. MISSION CAPABILITIES

The MCG System is capable of controlling unmanned vehicles at high altitudes, in low-level flight, beyond-the-horizon missions, and in extended range applications. It may also be used for landings and takeoffs of drone vehicles. The system is a versatile integrated system in that it can track a data transponder equipped vehicle, command the vehicle, and receive and utilize a telemetered return from the vehicle involved. With this capability and versatility, the system lends itself to applications in the drone guidance field, the surveillance field, recovery of orbital vehicles and boosters, and basic instrumentation applications. A particular application may require the use of only a portion of the MCG System while others may require the full system or even extensions of the present system. However, all of the above applications can be satisfied using the basic MCG concept as a starting reference. This section is an analysis of the current and potential utilizations of the system.

1. Service Drone Aircraft

A service drone aircraft is a normally manned and operational type aircraft that has been converted to drone or unmanned status. QB-17, QF-80, and QB-47 are examples of manned aircraft that have been converted to contain the MCG data transponder. The B-17 was the vehicle first used in testing the feasibility of the experimental MCG System. The QF-80 was next modified to contain the data transponder. It has been flown as a manned test vehicle for approximately two years. During this period, it was used for takeoff and landing studies which conclusively showed that the ground director was capable of meeting landing and takeoff requirements. It was also used as a test vehicle for operational evaluation of data transponder equipment at the Holloman test range during which time 84 QF-80 missions were conducted. Most recently, operations are being

conducted at the Eglin Gulf Test Range where QB-47 aircraft are being flown to evaluate the low-level capabilities of the Bomarc "B". This is being accomplished with MCG in the relay mode of operation. An actual countdown and flight plan is presented in succeeding paragraphs to show the utilization of the QB-47 service drone aircraft to support this Bomarc requirement.

These test vehicles represent a diversified class of aircraft. The QB-17 is a multiengine propeller-driven aircraft; the QF-80 is a single engine subsonic jet vehicle; and the QB-47 is a multiengine jet aircraft. With this versatility of applications, it is apparent that only the simplest of modifications to the command and data allocations are necessary to adapt MCG to a variety of vehicles. All of the previously used vehicles are subsonic. One significant factor is that with tracking capabilities of 12 to 15 degrees per second MCG enables the system to track targets with speeds in excess of Mach 20 when at the range of 25 nautical miles. Therefore, MCG is definitely capable of tracking and controlling supersonic vehicles such as the F-104, F-105, and F-106 should such a requirement exist. The primary applications of the service drone aircraft have been for AEC evaluation and for target application for such vehicles as Nike, Hawk, Bomarc "A", Bomarc "B", Falcon, Sidewinder, and GAR-type rocketry. Service drones play an important role in the development programs of such systems as these.

a. Description of an Actual Mission

In order for the unfamiliar reader to better understand the sequence of events that take place in conducting a typical mission, a description is provided. The mission described is a QB-47 low altitude flight to evaluate the Bomarc "B" low altitude intercept capability. Equipment coverage capabilities for specified locations are shown, along with an actual countdown and flight plan. Equipment checkout procedures and emergency in-flight procedures are also given. The ARW (UHF

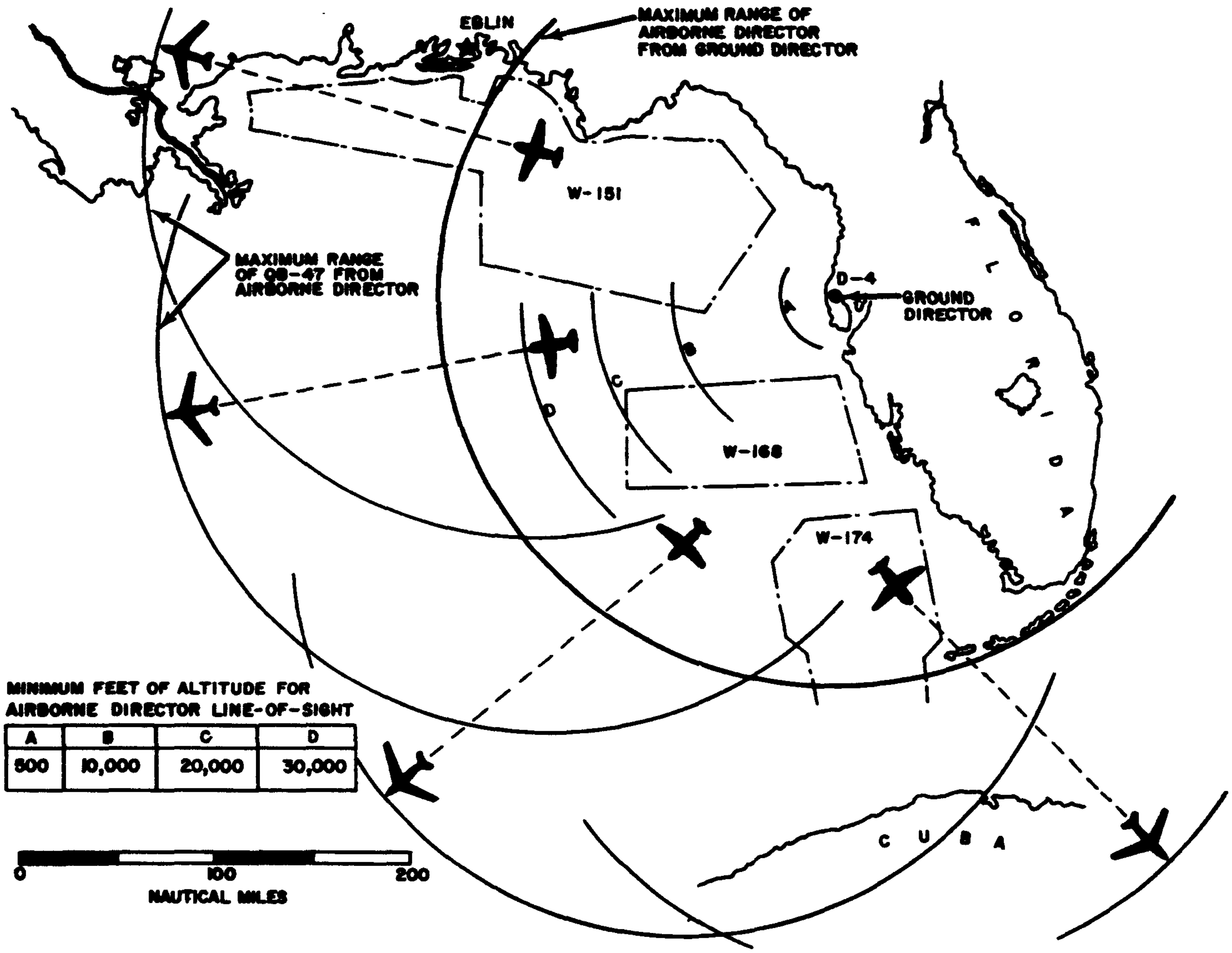
radio) guidance equipment is used in this particular application since only limited usage of MCG was desired for this mission. MCG can be readily extended to encompass the whole mission.

(1) Coverage

Optimum use of present MCG ground and airborne equipment is obtained by locating the ground director at site D-4, Anclote Point, Florida, and the airborne director at Eglin Air Force Base. The range coverage shown in figure 4-3 is realized when the airborne director is positioned at the various points indicated. It should be stated that the maximum ranges shown are conservative and the radar line-of-sight altitudes are the minimum altitudes required by the airborne director to maintain contact with the ground director. The QB-47 drone, however, may be controlled from a minimum altitude of approximately 500 feet to its maximum cruising altitude.

A checkout procedure is followed when qualifying a QB-47 for a controlled nullo flight. On the day preceding the planned mission, the entire complement of QB-47 electronic equipment, including the airborne and ground director equipment, is ground tested and inspected. This is followed by a complete maintenance preflight check including fueling and necessary mechanical testing. At the conclusion of the preflight, the QB-47 is flown for a two-hour in-flight test checkout of all subsystems. During this in-flight check, the airborne director conducts routing airborne command control checks with the ground director and the QB-47 drone. At the completion of the in-flight check, the QB-47 is qualified or unqualified for nullo status and returns to base for correction of any equipment discrepancies. If qualified, a complete postflight maintenance check is made, and the QB-47 and airborne director are refueled.

The ARW (UHF radio) guidance system controls the landing and takeoff of the test vehicle. Transfer of control to MCG is automatic when the ARW removes its carrier and



MINIMUM FEET OF ALTITUDE FOR AIRBORNE DIRECTOR LINE-OF-SIGHT

A	B	C	D
500	10,000	20,000	30,000

FIGURE 4-3 CONSERVATIVE RANGE OF MCG OPERATING IN THE RELAY MODE

an MCG signal is present. Three modes of control and the carrier fail sequence associated with each are discussed below:

- Mode One (ARW in control, AN/APW-20 and AN/APW-22 beacon ON). If operating in mode one, carrier of AN/ARW-1, AN/ARW-2, and AN/APW-20 will automatically transfer command control to MCG if MCG carrier is present. If MCG, ARW, or APW carrier is not present, the QB-47 will execute a climbing left circle turn and continue circling upon reaching 20,000 feet.

- Mode Two (ARW and AN/APW-20 in control, AN/APW-22 beacon ON). Same as Mode One.

- Mode Three (ARW and AN/APW-22 in control, AN/APW-20 beacon ON). If operating in mode three, carrier failure of AN/ARW-1, AN/ARW-2, AN/APW-20, and AN/APW-22 shall cause the QB-47 to climb to radio line-of-sight altitude, up to 20,000 feet, in a left circle turn. If control is not regained, the drone will orbit in a left circle turn at a preset airspeed.

On the actual day of the mission, a confidence type of ground check is performed to cover all subsystems. The airborne director then takes off and makes a final check with the drone and proceeds to check with the ground director. When the check is complete, the airborne director proceeds to its rendezvous orbit area and waits the delivery of the QB-47 by the ARW command guidance air director (T-33). Upon arrival, verified command and flight data checks are made between the airborne director and the QB-47 prior to continuing further down range. During the checkout period a pace aircraft determines

if extensive barometric pressure changes have occurred down range before proceeding. When all conditions are satisfied, the mission continues with the relay mode of operation established, and the pace aircraft returns to base. Control of the QB-47 is transferred to direct control by the ground director while the airborne director obtains a position fix to update its AN/APN-99 navigational equipment. The airborne director then climbs to its mission altitude where transfer is again made to the relay mode of operation. The mission then continues through the predetermined pattern at the coordinates required as defined for the particular Bomarc mission. Upon completion of the mission, normal recovery procedures are initiated to return the QB-47 drone to the base. An actual countdown and general mission flight plan are presented below and are further illustrated in figure 4-4.

COUNTDOWN

H-2 days: Definite mission requirements. From Test Operations Directive.

H-1 day: Preflight of aircraft for ferry to Field No. 3 (Nullo takeoff field).

*T.O. - 8:00	Preflight of QB-47's entire systems by C&E personnel.
T.O. - 5:00	Aircraft preflight by maintenance personnel. E.O.D. install and/or check primer cords.
T.O. - 2:45	A/C maintenance, top off with water alcohol.
T.O. - 2:00	Pilot's preflight of aircraft.
T.O. - 1:00	GC-130 takeoff and checkout AN/TPW-1.

*Only if determined necessary by PGLED. PGLED will be responsible for notifying PGLMC when preflight is not required. PGLMC will notify PGLB and C&E preflight is not required.

	T.O. - 0:00	Two-hour flight check of QB-47 terminating at Field No. 3. (If aircraft develops problems, notify Hotel, building 100, and Black Dart for maintenance and/or possible replacement.) This will include all MCG commands and data check.
	T.O. +2:00	QB-47 land Field No. 3. GC-130 land main base.
	T.O. +5:00	Complete postflight by maintenance and clearing of aircraft discrepancies and any C&E malfunctions including MCG and GC-130. Refuel aircraft - refueling vehicle to remain empty for possible defueling.

**DT-33 aircraft ferried to Field No. 3 no later than 1500 hours for mission.

H-0 day:	T.O. - 6:30	Aircraft maintenance preflight instrumentation installation and checkout. Pilot system checkout.
	T.O. - 2:45	Top off with water alcohol.
	T.O. - 2:00	Pilot's preflight.
	***T.O. - 1:50	MRW-5 in position and checkout. Drone operations will advise on desired position.
	T.O. - 1:30	FMIC aircraft airborne and monitoring.
	T.O. - 1:00	Arresting barrier installed and checked by DME. MRW-5 power on.
	T.O. - 1:00	Scramble GC-130. QB-47 start engines.
	T.O. - 0:50	QB-47 taxi.
	T.O. - 0:45	DT-33's start engines and taxi.

**No later than 1500 is desired - Extenuating circumstances will cause changes.

***Tower must be manned at least 1:55 before takeoff to allow for MRW-5 and Hero checkout. Drone operations will place this requirement on AACS.

T.O. - 0:40	DT-33's, QB-47, MRW-5, and Hotel checkout, GC-130, TPW-1 relay check.
T.O. - 0:35	E.O.D. circuit checkout.
T.O. - 0:30	DT-33's takeoff.
T.O. - 0:15	DMC notify Base Operations, Tower Personnel, Fire Department to sound alert for evacuation of building.
T.O. - 0:10	E.O.D. install detonators.
T.O. - 0:00	QB-47 takeoff.
T.O. X Hours	Recover QB-47 at Field No. 3. Airborne DT-33's land main base. Spare DT-33 return to main base. GC-130 land main base.

FLIGHT PLAN

A. SCOPE

To conduct a simulated low-level mission profile.

B. TEST OBJECTIVES

To control the QB-47 drone at low altitudes.

C. EQUIPMENT REQUIRED

The following equipment is required to perform this mission:

1. MCG airborne director (GC-130).
2. QB-47 (transponder equipped).
3. MCG ground director.
4. DT-33 director aircraft (pace vehicle).

D. PERSONNEL REQUIRED

1. QB-47 air crew (APGC).
2. GC-130 airborne director air crew (APGC).

3. Two QB-47 drone control operators to function as beeper controllers, one in the ground director at D-4 and one in the airborne director (APGC).
4. Two radar operators, one in the ground director and one in the airborne director (Sperry).
5. DT-33 air crew (APGC).
6. Ground handling personnel for airborne director, QB-47 and DT-33.

E. SERVICES REQUIRED

The following services are required to support all missions:

1. Primary 115-volt, 60-cycle power at D-4.
2. Signal 4 timing at D-4.
3. Ground handling equipment for the GC-130, QB-47, and DT-33.
4. Digital and oscillograph data processing (post mission).

F. RADIATION TIME

Approximately six hours of radiation time will be required for this mission.

G. MISSION DURATION

The duration of this mission will be approximately four hours and will be conducted on range, in area W-168.

H. PROFILE DESCRIPTION (figure 4-4)

1. GC-130 takeoff. Conduct command and flight data check with QB-47. Pass over Eglin Omni and set Navigational System AN/APN-99. Take heading of 102 degrees magnetic (Cross City VOR) and commence climb to 30K feet.

2. Establish radar and radio contact between D-4 and airborne director as early as possible. Set Navigational System on passing over Cross City VOR (position 1).
3. Airborne director take heading to Lakeland VOR. Break MCG contact between ground director and airborne director.
4. QB-47 and DT-33 take off and establish heading of 104 degrees magnetic at 25K feet. DT-33 assume radio control of QB-47. Ground director establish MCG contact with QB-47 (position 2).
5. Conduct command and flight data check with QB-47. Transfer control of QB-47 to ground director (position 3). DT-33 return to Eglin.
6. Ground director establish QB-47 in race track pattern west of D-4 until airborne director is in position and passively tracking the QB-47 (position 4).
7. Shift to relay mode and conduct command and flight data check; after the airborne director passes over Lakeland VOR, set Navigational System and take heading of 155 degrees magnetic. Commence letdown of drone to 10K feet (between positions 4 and 5).
8. Airborne director control drone on a parallel path and abeam of the airborne director at a range of approximately 100K yards. When the airborne director is approximately 220K yards from the ground director, the airborne director shall commence a turn to starboard (position 5),

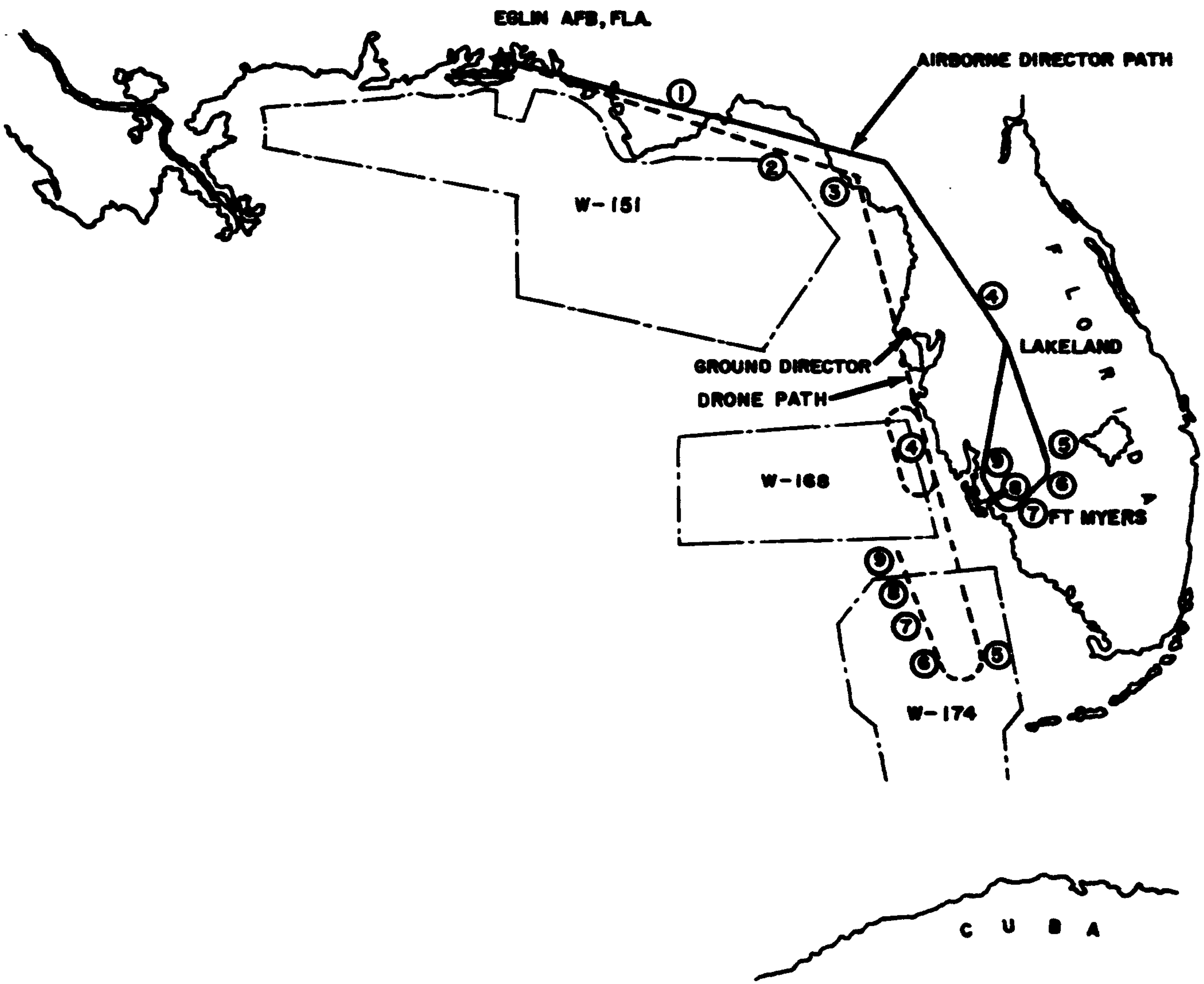


FIGURE 4-4 MCG QB-47 FLIGHT PLAN PROFILE

and establish heading for Ft. Myers VOR. Command drone in starboard turn to heading of 164 degrees.

9. Commence letdown of QB-47 to 2K feet (position 6) to reach 2K feet (position 7).
10. Airborne director cross over Ft. Myers VOR and establish heading of 327 degrees magnetic, maintaining the QB-47 abeam at 100K yards range.
11. Let down the QB-47 to 500 feet altitude and hold (position 8).
12. Climb QB-47 to 20K feet (position 9). Control QB-47 to return to Eglin. DT-33 establish contact with drone.
13. DT-33 control drone to landing pattern Auxiliary Field No. 3.
14. Airborne director return to base.
15. Ground control land QB-47.
16. End of mission.

(2) Checkout Procedures

In previous paragraphs, reference was made to checkout tests and procedures performed prior to conducting the actual mission. A total of 5 hours and 30 minutes is required to check out MCG equipment on the day prior to the mission, and a total of 2 hours and 30 minutes is required for MCG checks on the day of the mission. The MCG component breakdown of these checkout periods is presented in table 4-2.

TABLE 4-2

EQUIPMENT CHECKOUT PERIODS

Component	Premission Checks (hours)	Preflight Checks (hours)
Data transponder in drone	1.0	0.5
Airborne director	2.5	1.0
Ground director	2.0	1.0

(a) Data Transponder Premission Checks

On the day before a mission, the data transponder is tested for its response to all commands it normally receives during a mission. Refer to table 4-3. All power, frequency, receiver sensitivity, response to interrogations, and readouts of simulated flight data are measured using the radar and data processing test set. The drone simulator test set provides all of the necessary flight data. The drone simulator test set has 6 proportional dials and 16 on-off switches to simulate the 6 proportional channels and 2 on-off channels of data. The simulated data does not check the QB-47 transducers themselves but indicates that the associated electronic equipment within the data transponder is working properly. Actual transducer checks and calibrations are made during the QB-47 qualification flight.

(b) Data Transponder Preflight Checks

The one-half hour preflight check is a condensed premission test. It is considered a confidence check during which power and sensitivities are measured.

TABLE 4-3

CURRENT MCG QB-47 COMMAND AND DATA ASSIGNMENTS

Command Sent	Aircraft Light Indicator	Aircraft Response	Flight Data In Director
1. Left	Left On	Wheel Left	None
2. Right	Right On	Wheel Right	None
3. Circle Turn On	None	None	C/T Light On
4. Left	Left On	Wheel Left	No Change
5. Navigation Turn	None	Wheel Centers	C/T Light Off
6. Circle Turn	None	None	C/T Light On
7. Right	Right On	Wheel Right	No Change
8. Navigation Turn	None	Wheel Centers	C/T Light Off
9. Up	Up On	Wheel Aft	No Change
10. Down	Down On	Wheel Forward	No Change
11. ACE (On)	ACE On	Wheel Centers	ACE On Light On
12. Direct Pitch	ACE Off	None	ACE Light Off
13. A/S Pitch On	A/S Pitch On	None	A/S Pitch Light On
14. Throttle Interlock On	None	None	Throttle Interlock Light On
15. Increase	None	Throttles Advance	No Change
16. Decrease	None	Throttles Retard	No Change
17. Throttle Interlock Off	None	None	Throttle Interlock Light Off
18. A/S Throttle On	A/S Pitch Off A/S Throttle On	None	A/S Pitch Light Off A/S Throttle Light On
19. Cruise A/S On	None	A/S Reference to 240K	A/S Reference to 240K

TABLE 4-3 (cont)

Command Sent	Aircraft Light Indicator	Aircraft Response	Flight Data In Director
20. Cruise A/S Off	None	None	No Change
21. Increase	None	A/S Reference Increase	A/S Reference Increase
22. Decrease	None	A/S Reference Decrease	A/S Reference Decrease
23. A/S Throttle Off	A/S Throttle Off	A/S Reference to Zero	A/S Reference to Zero
24. Antenna Select	None	None	Antenna Tail Light Off Drop in AGC
25. Antenna Select	None	None	Antenna Tail Light On Original AGC
26. Flight Data Blank	None	None	All Flight Data Off
Manual Control - Raise Wing Flaps			
27. R/S Arm	None	None	R/S Arm Light On
28. Explode	Four Explode Lights On	Explode Solenoids In	Arm Light Off in 2.3 Seconds
Manual Control - Lower Wing Flaps			
NOTE: The range safety arm circuit has a hold in delay which will hold the range safety circuit armed for 2.3 seconds after the "R/S ARM" command is released.			
29. AKT-7 Transfer	None	None	UKR-2 System Transfer
30. AKT-7 Calibration	None	None	UKR-2 System Calibration
31. Engine Select	None	None	UKR-2 Engine Select
32. Fuel Select	None	None	UKR-2 Fuel Select

(c) Airborne Director Premission Checks

The radar and data processing test set is also used to check the airborne director interrogator's power, frequency, receiver sensitivity, acceptability of command, and receipt of flight data just as it did for the data transponder in the drone in accordance with an approved test procedure. At the completion of the check, an actual tracking check is made using the range and tracking test set. This test set is placed approximately 100 to 200 feet from the airborne director. The tracking system is made to "lock-on" (interrogate) the test set which contains a transponder beacon and range computer. After acquisition, known range inputs are inserted into the test set to check the ranging function. At the conclusion of these tests the radar and data processing test set is connected to the relay transponder within the airborne director. Power, frequency, receiver sensitivity, response to commands, and flight data readouts are tested as previously performed for the data transponder. The plotting function is then tested by activating the AN/ASN-7 portion of the AN/APN-99 navigational equipment (to provide latitude and longitude reference inputs), by simulating target range with the range equipment and by rotating the antenna to provide the direction reference to the drone. All equipment is normally checked in approximately 2-1/2 hours.

(d) Airborne Director Preflight Checks

The preflight check is a much simplified premission check and is usually accomplished in approximately one hour in accordance with an approved procedure. What is normally looked for are inadvertent alignments or variations from the premission checkout. Range maps are placed on the plotting boards.

(e) Ground Director Premission Checks

The ground director premission check is identical to the airborne director checks, with the radar and data processing test set, and the range and tracking test set. The same radar power, frequency, and response checks are made to determine that the command transmissions from the ground director are correct and the insertion of the appropriate flight data bits result in the proper deflection of the data indicators and plotting pens. Again, the range and tracking test set is remotely located from the ground director which is made to acquire the radiating horn on the test set. During this test, the second plotting board pen (relayed drone position) can be tested by simulating the relay mode of operation and by using the radar and data processing test set to insert drone X-Y position references. A complete check list exists for the ground director similar to that of the airborne director which completely checks all elements including the incoming voltages, currents, and frequencies to the ground director.

(f) Ground Director Preflight Checks

The one-hour ground director preflight check is a condensed premission check to assure that the power levels are correct and the frequencies are within tolerances. The plotting board is checked again to see that the coordinates are in proper alignment. The mission map is placed on the plotting board.

(g) Checkout Conclusions

At this time, 30 QB-47 missions have been conducted at the Eglin Gulf Test Range where the ground director is located 260 air miles from the airborne director and QB-47 drone. Because of the distance, the ground director can only be checked using the applicable test equipment. In all these missions the ground director has never failed to acquire the vehicle to be tracked when it came within radar line-of-sight.

b. Emergency In-Flight Procedures

When an emergency arises during a manned flight, the safety pilot can assume manual control. However, one of the most critical emergencies that can occur during a nullo (or unmanned) flight is loss of carrier. Circuitry has been incorporated in the QB-47 to program the aircraft to a higher altitude position where the carrier can be re-established from the ground director. If the drone loses its carrier, it will execute a left circle turn while climbing to 20,000 feet. Upon reaching 20,000 feet, the QB-47 will continue to make left circle turns at a preset airspeed. If the QB-47 is within 200 miles of the ground director, it can assume control and fly the QB-47 to a designated area to meet the DT-33 ARW landing control aircraft. If the situation should arise where the ground director loses track of the airborne director, the airborne director can control the drone directly and can return the QB-47 to base.

2. Q-Type Vehicles

MCG was originally designed for Q-type vehicles but has actually seen more service with service drone-type vehicles than with the Q-type. The data transponder was originally installed in the XQ-2C and the XQ-4B vehicles on two separate programs. Both were successful from a control and guidance standpoint. These programs were completed, but not without some degree of difficulty during the early and inexperienced stages. The final result was that vehicles with supersonic speed capabilities can be readily controlled using the MCG System. Operations conducted at Holloman Air Force Base showed that the MCG ground director was able to control the vehicles in all flight configurations, at all altitudes, all airspeeds, and at all ranges encountered at that facility. The specific results of the programs covering the period of February 1960 through March 1961 are

documented in Sperry publication LJ-1271-0031, entitled "Summary and Activity Report of Microwave Command Guidance System", dated March 1962.

3. Navy

The Navy, in addition to the Air Force, can effectively utilize MCG for both service and Q-type drones, Investigations have indicated that the Navy has an increasing requirement for what is termed a "second generation guidance and control system".

U.S. Navy target requirements vary widely from the small inexpensive targets used for fleet training to the converted or service drone aircraft target and high performance Q-type drone for R&D testing. A lower cost data transponder is presently in the development stage (on a company funded basis) with future application directed toward usage with Navy and other type targets. This data transponder will have operational characteristics equivalent to the present data transponder and is designed specifically for low cost and reduced size.

The Navy's missions are categorized into two basic types: in one the target is used for gunnery practice, and in the other the target is used in missile system exercises. The gunnery mission is a short range mission where the target is launched from a naval ship and controlled from the ship within a visual range of 15 to 20 miles. Missile missions usually have a range of 150 miles or longer where the target is air launched and controlled from within a ground director or an airborne director station. An air launch scheme with the airborne director could be applied to the short gunnery range mission at chosen ranges to the ship. In this application, the airborne director can carry the vehicles to the ship, air launch the vehicle, and control it when the ships are within specific range boundaries such as Roosevelt Roads, Puerto Rico.

Missile target ranges up to 150 miles are currently required by the Navy with 200 miles desired. Mission altitudes vary from 0 to 50,000 feet, with a future requirement of 80,000 feet, with speed variations from 150 knots to Mach 3. MCG has the capability of meeting these requirements with only simple modifications being necessary for full utilization of the system as attested by experiences gained in flying the QB-17, QF-80, QB-47, XQ-2C, and XQ-4B. These aircraft have characteristics equivalent to such Navy vehicles as the F9F, Q-2C, Regulus 1, and other high performance vehicles, and are therefore considered to be within the realm of controlability by MCG.

Naval operational studies have been conducted particularly with regard to the Roosevelt Roads range in Puerto Rico. The range boundaries are shown in figure 4-5. With the ground director located on high terrain west of the Roosevelt Roads NAS (northeast of the town of Juncas), sea level flights of the drone can be controlled to a range of 75 nautical miles. At this location, drone flights can be controlled over both the Alfa and Bravo target areas to 200 nautical miles as shown by the coverage capability in figure 4-5.

Landings and takeoffs of F9F and F8U type drones can be accomplished through use of a remote site located at the edge of the runway. The equipment involved will consist of a data transponder transmitter with command control capabilities only. When the ground director returns the vehicle to within approximately 10 miles of the base area, control can be transferred from the ground director to the remote site. The remote station will then accomplish a visual landing. A TV-2 type chase aircraft (equivalent to Air Force T-33) may also be employed when equipped in a manner similar to the remote runway station. Each of these stations will contain an omnidirectional antenna for command control.

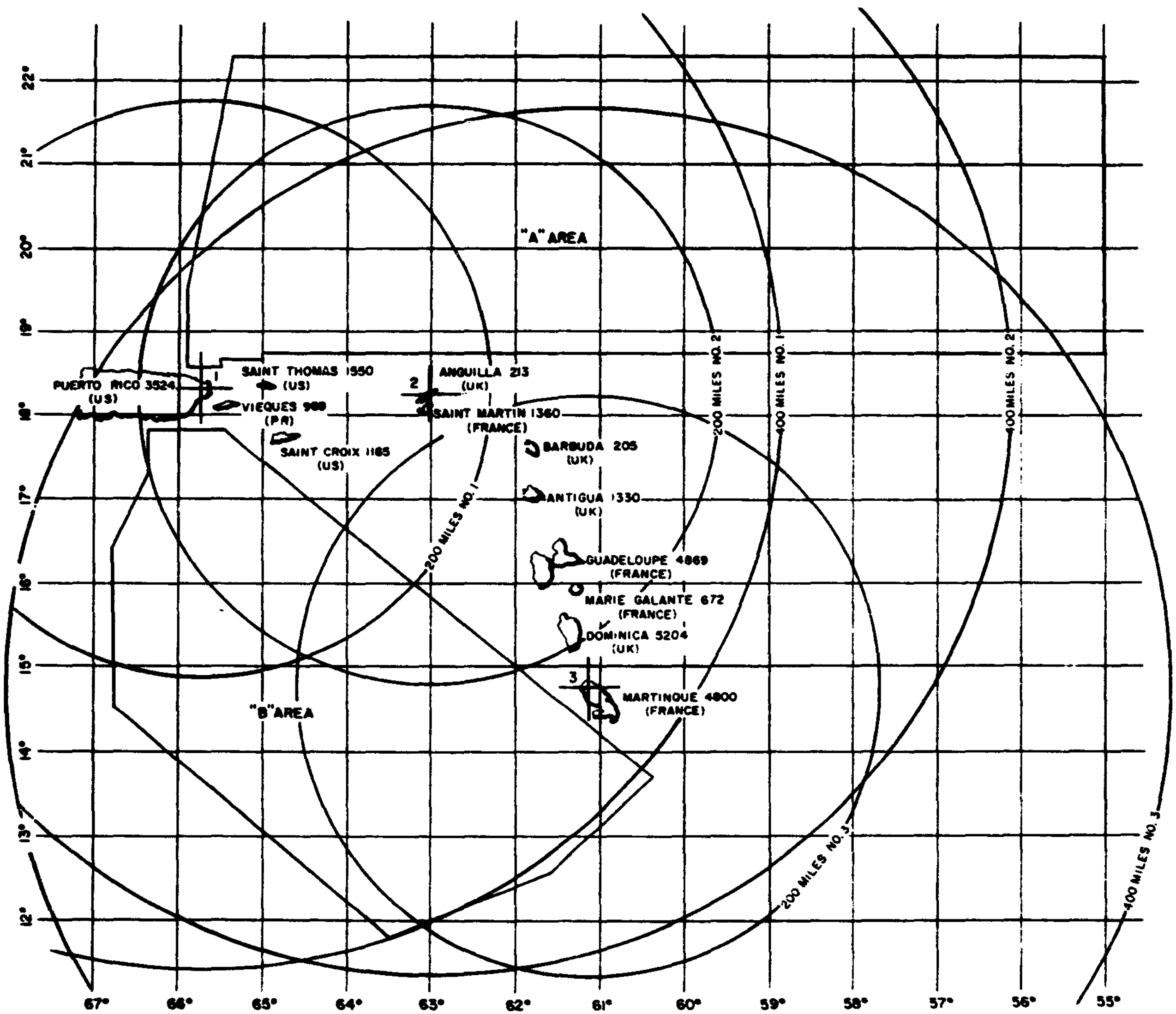


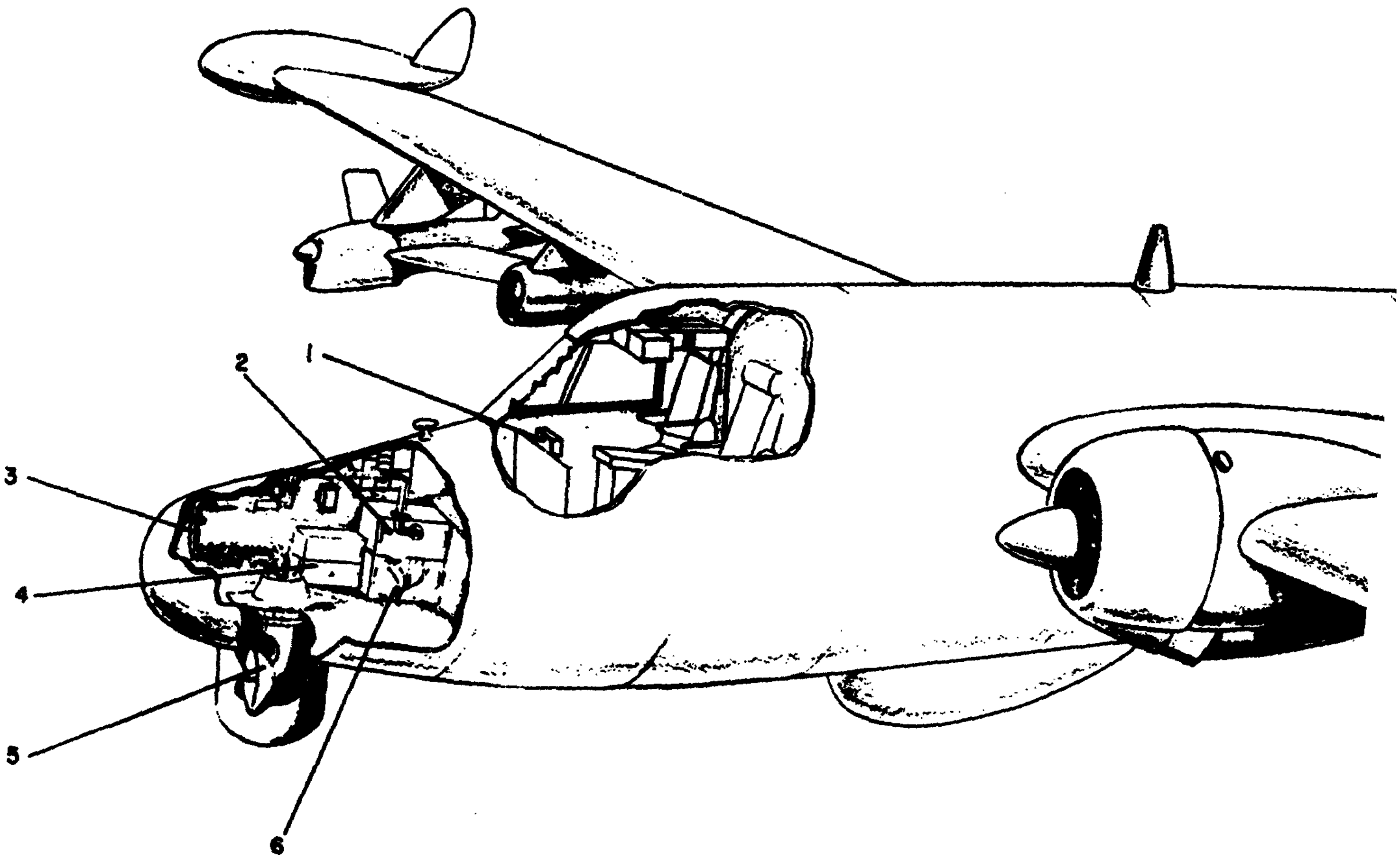
FIGURE 4-5 DIRECTOR STATION LOCATION IN THE ROOSEVELT ROADS NAS AREA

Extended operations, also reflected in figure 4-5, can be accomplished by locating ground stations down range along with an airborne director of the P2V class. The ground complex will be virtually identical to the current ground director. A considered installation of the airborne director equipment in the P2V vehicle is shown in figure 4-6. The down range covering capability is possible if the ground director is located on those islands that are within close proximity to either the Alfa or Bravo zones; particularly with regard to the Alfa zone. Location of a ground station on the Island of Anguilla (United Kingdom) will afford greater coverage over the Alfa range. Locating the equipment on either the Island of Dominica (United Kingdom) or Martinique (France) will provide coverage extension over the Bravo zone and will also provide good low-level drone flight control due to the higher elevations of these sites (5,204 feet and 4,800 feet, respectively). Additionally, a logical extension of the relay range capability exists as is reflected in figure 4-5.

4. Surveillance Applications

Army drone system missions fall into two classes: those for surveillance and reconnaissance purposes, and those for other tactical purposes such as delivery of a package to some point in enemy-held territory. Each class of mission falls into two categories which affect the guidance and control system requirements. These categories may be defined as long and short range missions. Long range is considered to be beyond the radar line-of-sight.

Several characteristics of the guidance and control system are common to all missions while others are dependent upon the class and range of the mission in question. These characteristics are shown in table 4-4.



1. ANTENNA POSITION INDICATOR
2. RECEIVER TRANSMITTER
3. WAVEGUIDE ROUTING
4. EXISTING AIRCRAFT EQUIPMENT
5. TRACKING ANTENNA
6. AMPLIFIER DETECTOR

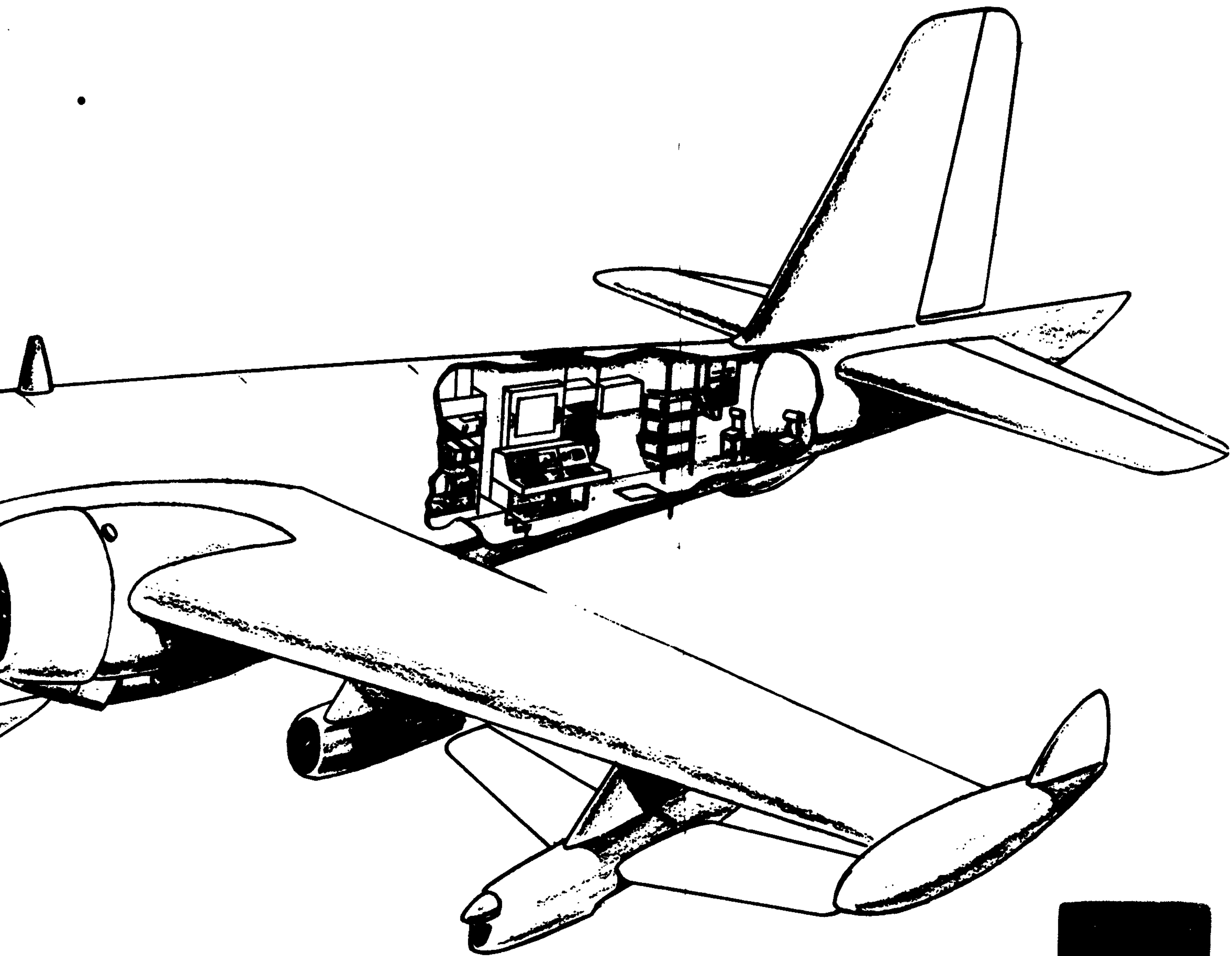
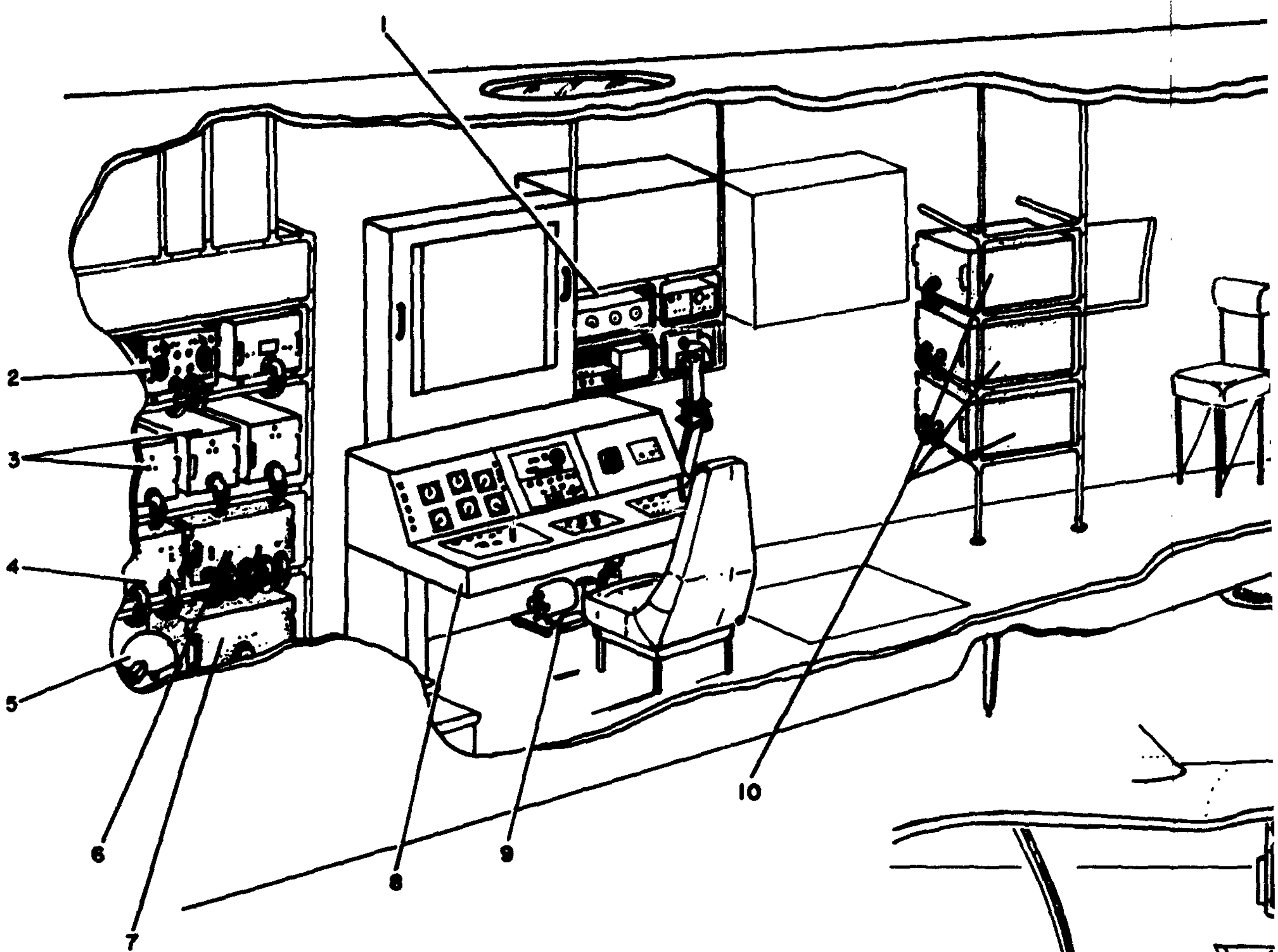
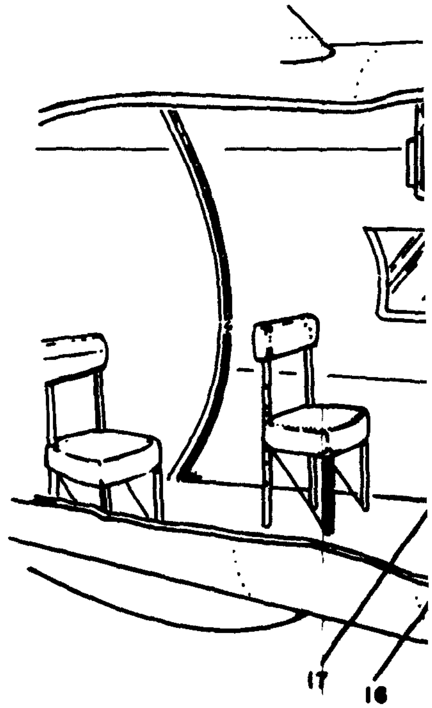


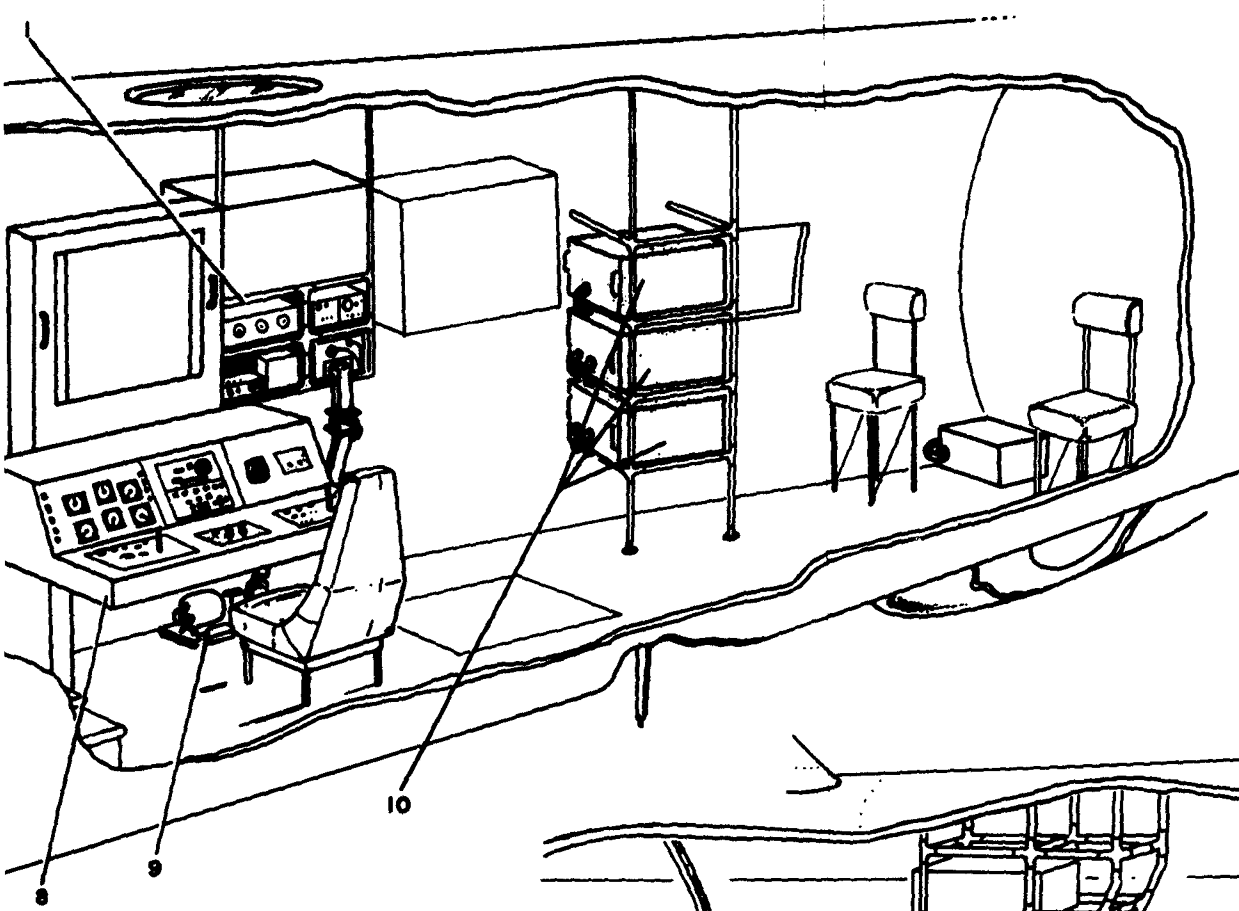
FIGURE 4-6 A CONSIDERED AIRBORNE DIRECTOR EQUIPMENT INSTALLATION IN A P2V VEHICLE (SHEET 1 OF 2)



1. RELAY TRANSPONDER EQUIPMENT
2. COMPUTERS
3. POWER SUPPLY
4. PULSE GENERATOR
5. VERTICAL GYRO
6. VIDEO DECODER
7. DIGITAL TO ANALOG CONVERTER
8. COMMAND CONSOLE
9. VACUUM PUMP
10. RANGE EQUIPMENT
11. ELECTRONIC CONTROL AMPLIFIER
12. PPI SCOPE
13. CONTROL INDICATOR
14. RADAR CONSOLE
15. ANTENNA CONTROL
16. ELEVATION INDICATOR
17. "R" SCOPE



FIGURE



SPONDER EQUIPMENT

LY
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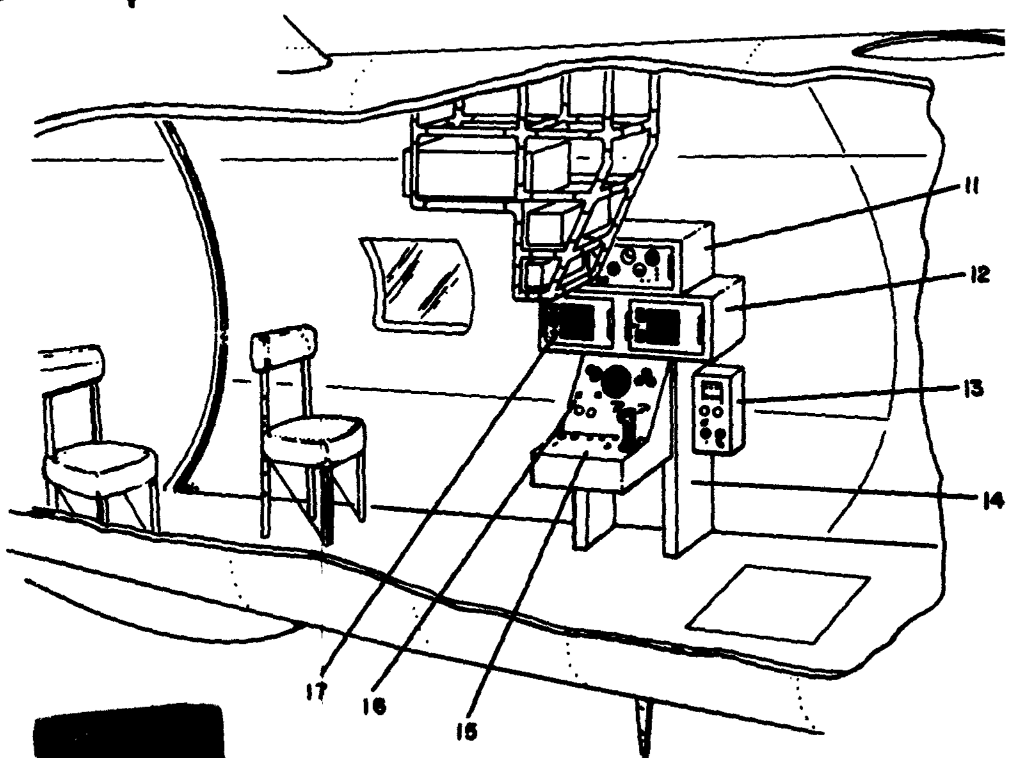


FIGURE 4-6 A CONSIDERED AIRBORNE DIRECTOR EQUIPMEN'
INSTALLATION IN A P2V VEHICLE
(SHEET 2 OF 2)

TABLE 4-4

GUIDANCE AND CONTROL REQUIREMENTS
FOR VARIOUS DRONE MISSIONS

Guidance and Control Characteristic	Short Range Surveillance	Short Range Tactical	Long Range Surveillance	Long Range Tactical
High accuracy	X	X	X	X
High security	X	X	X	X
High mobility	X	X	X	X
Over-the-horizon transmission			X	X
Two-way data link for control	X		X	
Data correlation	X		X	
Extensive computation	X		X	

Appropriate modifications to the basic MCG System will provide a base station from which over-the-horizon communication capability can be realized. These modifications also will provide a means of achieving transmission of surveillance sensor data through the basic link, provide a method of locating the target relative to the weapon without reference to an absolute position, provide a method of improving the already excellent security characteristics as enemy countermeasure capabilities are increased, and provide a means of correlating surveillance sensors with data representing the drone's geometric status.

Application of the system to such a vehicle as the SD-2 has been considered. The functions mentioned above can be performed by a system which consists of a modified ground director shown in figure 4-7 and a data transponder in the drone as depicted in figure 4-8.

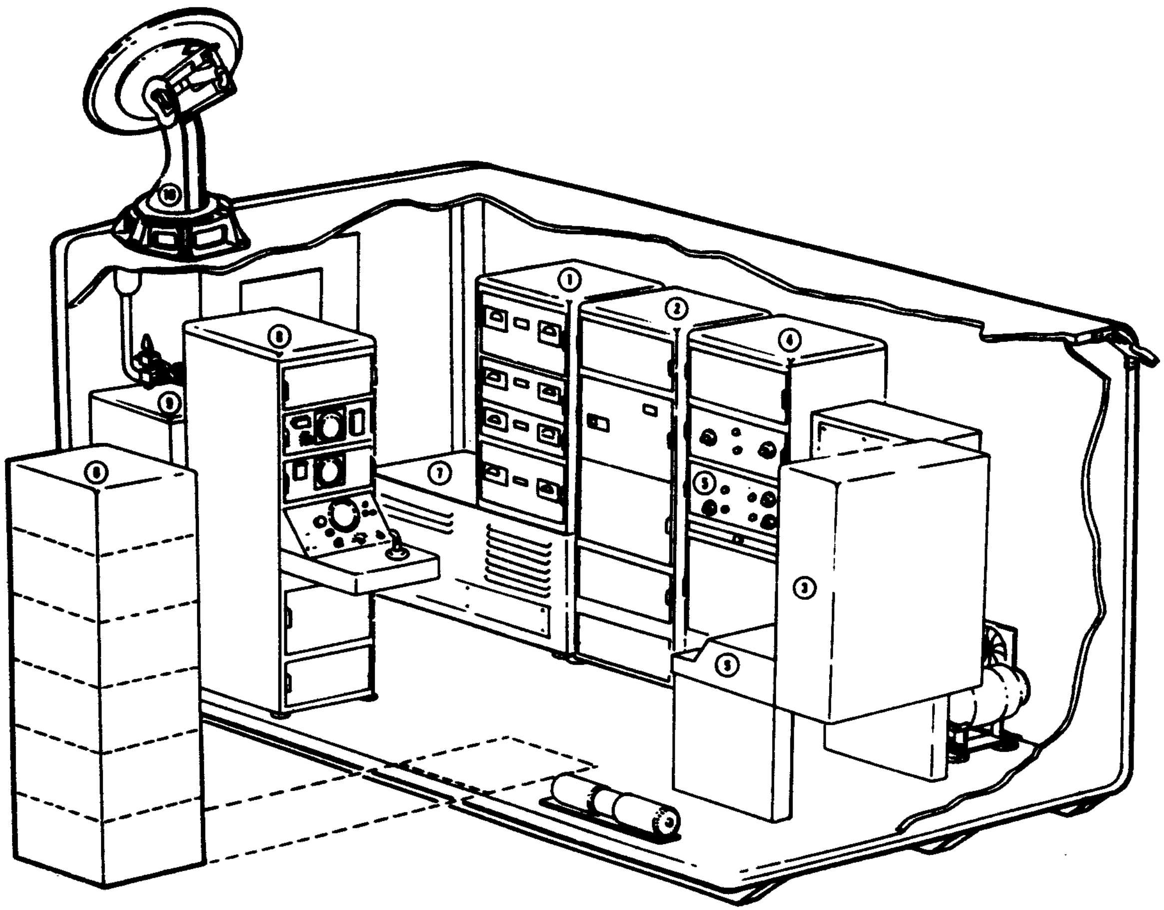


FIGURE 4–7 PROPOSED US ARMY GROUND DIRECTOR

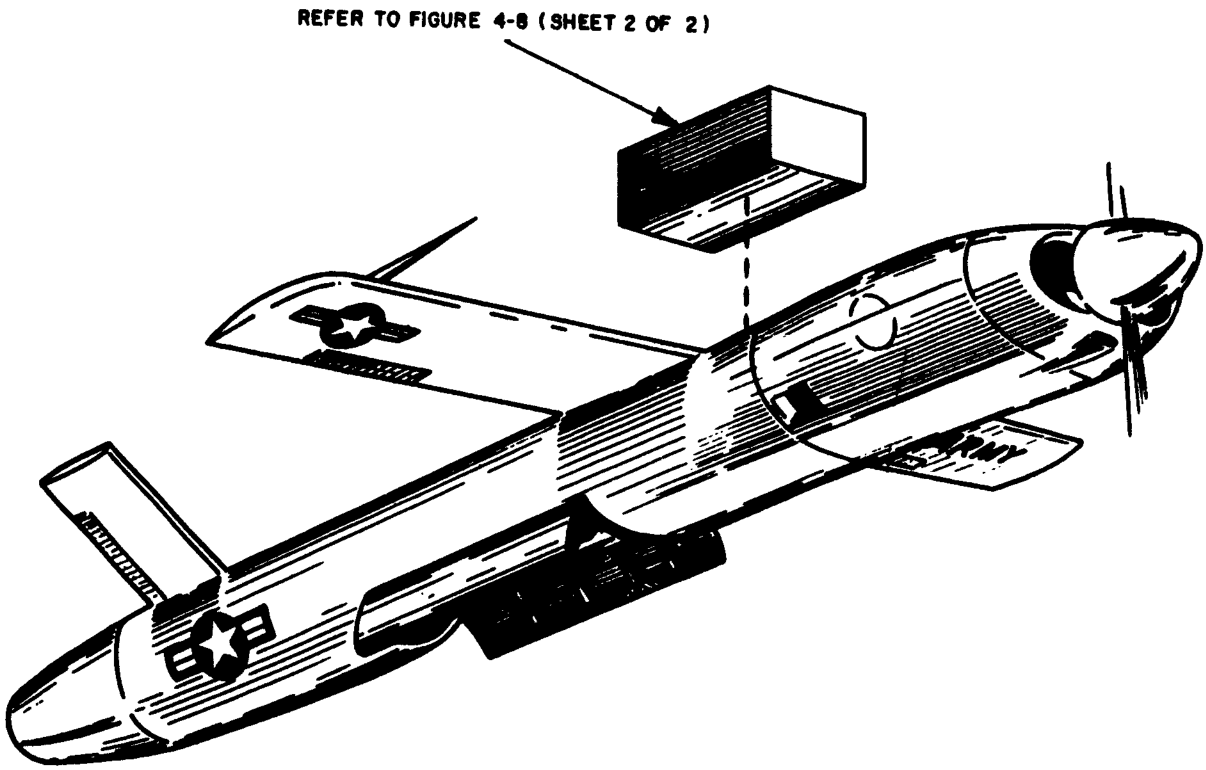


FIGURE 4-8 DRONE AIRBORNE EQUIPMENT (SHEET 1 OF 2)

1 FLIGHT PROGRAMMER $4\frac{1}{2} \times 7\frac{1}{4} \times 12\frac{3}{4}$

1 AIRBORNE REFERENCE OSCILLATOR $2 \times 4 \times 4\frac{1}{2}$

3 INSTRUMENT SERVO UNITS $2 \times 2 \times 4$

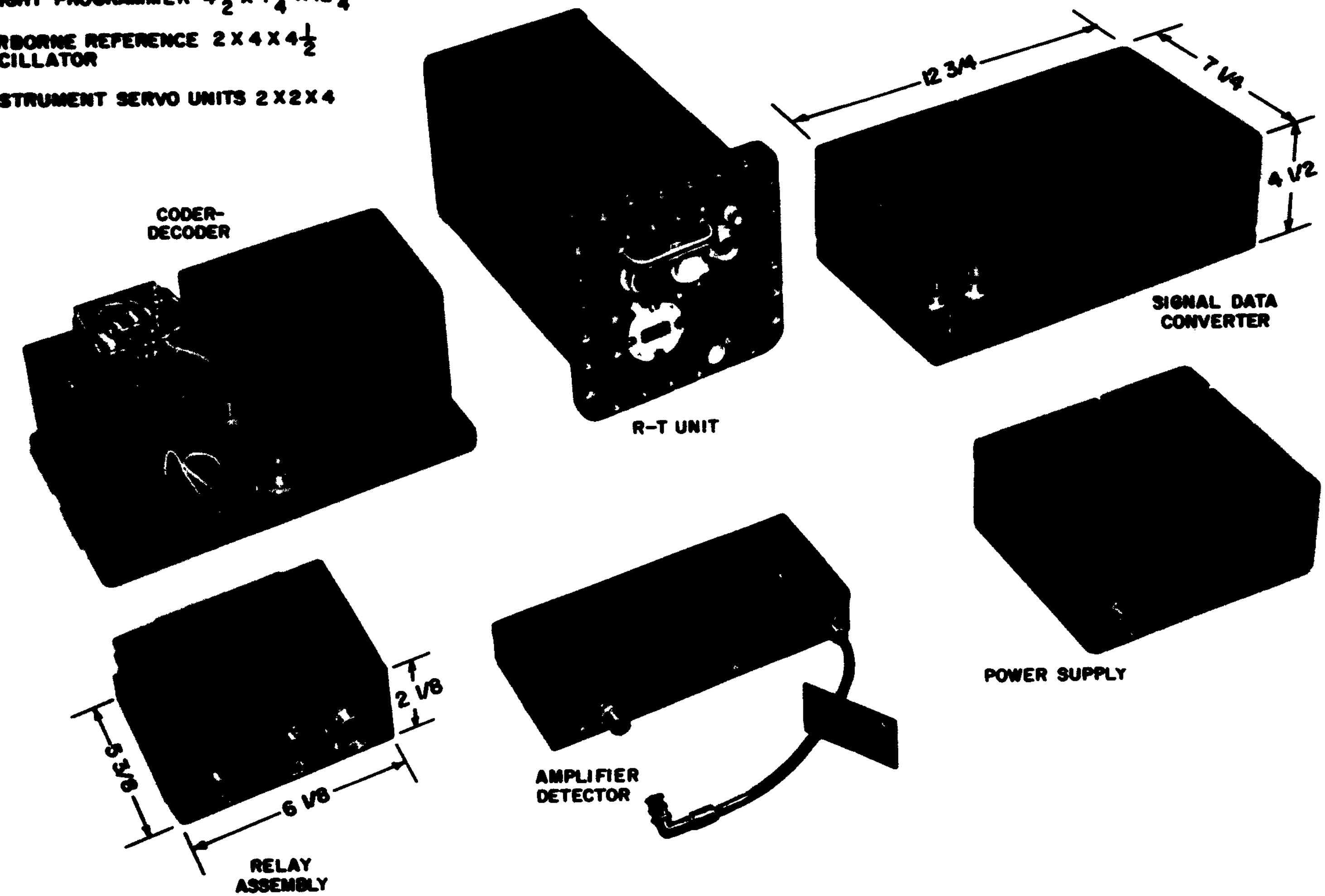


FIGURE 4-8 DRONE AIRBORNE EQUIPMENT (SHEET 2 OF 2)

The ground director station employs the basic PCM system developed for MCG. The PCM system has command and data handling capabilities similar to MCG. Command transmissions are somewhat different in that proportional commands are transmitted by means of a closed-loop data transmission system. The closed loop consists of two instrument servos, one in the ground director and the other in the drone's data transponder. Proportional reply data from the data transponder establishes a ground director reference value. A proportional command results in a command error signal relative to the received reference. The command error signal is transmitted as appropriate on-off signals to the drone's instrument servo. This servo is driven toward a setting until the reply data establishes a new reference corresponding to the commanded setting. No error signal is generated, but a pseudo-proportional command is generated.

When image correlation is required, a synchronizing signal at a rate of one synch-pulse per frame (which corresponds to a free-running frequency of an airborne reference oscillator) is provided from the ground director for the airborne reference oscillator. This oscillator provides image number data to either a sensor camera or a strip film camera. For the sensor camera, the reference oscillator drives an image number digital counter by way of a servo to provide an advance in image number approximately one digit per 0.8 second. Image correlation for the strip film camera is provided through a matrix and indicator lights for recording of the image number in binary form.

Operationally, mobility is afforded for battlefield area usage by requiring as little as two hours for setting up the vehicle and performing initial checkouts. Over-the-horizon control can be afforded through use of a relay station similar to the present MCG airborne director or with a vehicle such as an H-21 helicopter or aircraft such as the Caribou, Mohawk, or Choctaw. An application utilizing the H-21 helicopter is shown

in figure 4-9. Another means of over-the-horizon control that can be employed is to select a programmed flight mode which has been set into a programmer prior to flight. The programmer ultimately brings the drone back above the radar horizon, and subsequently the drone is acquired and control reverts to the director station. In the event the radar link is lost due to a malfunction or other cause, the return-to-base information (which has been computed continuously during the flight and stored in the drone) will be used to program the drone back to a previously selected recovery area. If the radar link can be re-established, the operator may resume control at any point.

The over-all position accuracy realizable in the ground director direct control mode is estimated to be 2.5 meters per nautical mile CEP (circular probable error) with a minimum value of 21 meters CEP (the low limit of the range equipment). Utilization of the relay mode will yield a result of 3.3 meters per nautical mile.

The drone antenna configuration, required to obtain optimum vehicle coverage, is a two-antenna system with one vertically polarized skirt dipole antenna mounted on top of the vehicle and a flush mounted H-slot antenna mounted on the belly. The resulting composite patterns are shown in figures 4-10 and 4-11. These patterns are based on measured free-space patterns of the two antennas used with the Q-2C drone.

5. Glider Recovery Applications

The versatility of the MCG System is highlighted by its entry into the orbital glider vehicle recovery field. Currently, it is planned to recover the unmanned Dyna Soar vehicle as they complete their "once-around" missions.

For this particular application, it is planned that the basic MCG System concept be employed with appropriate modifications to fulfill the mission requirements. These requirements

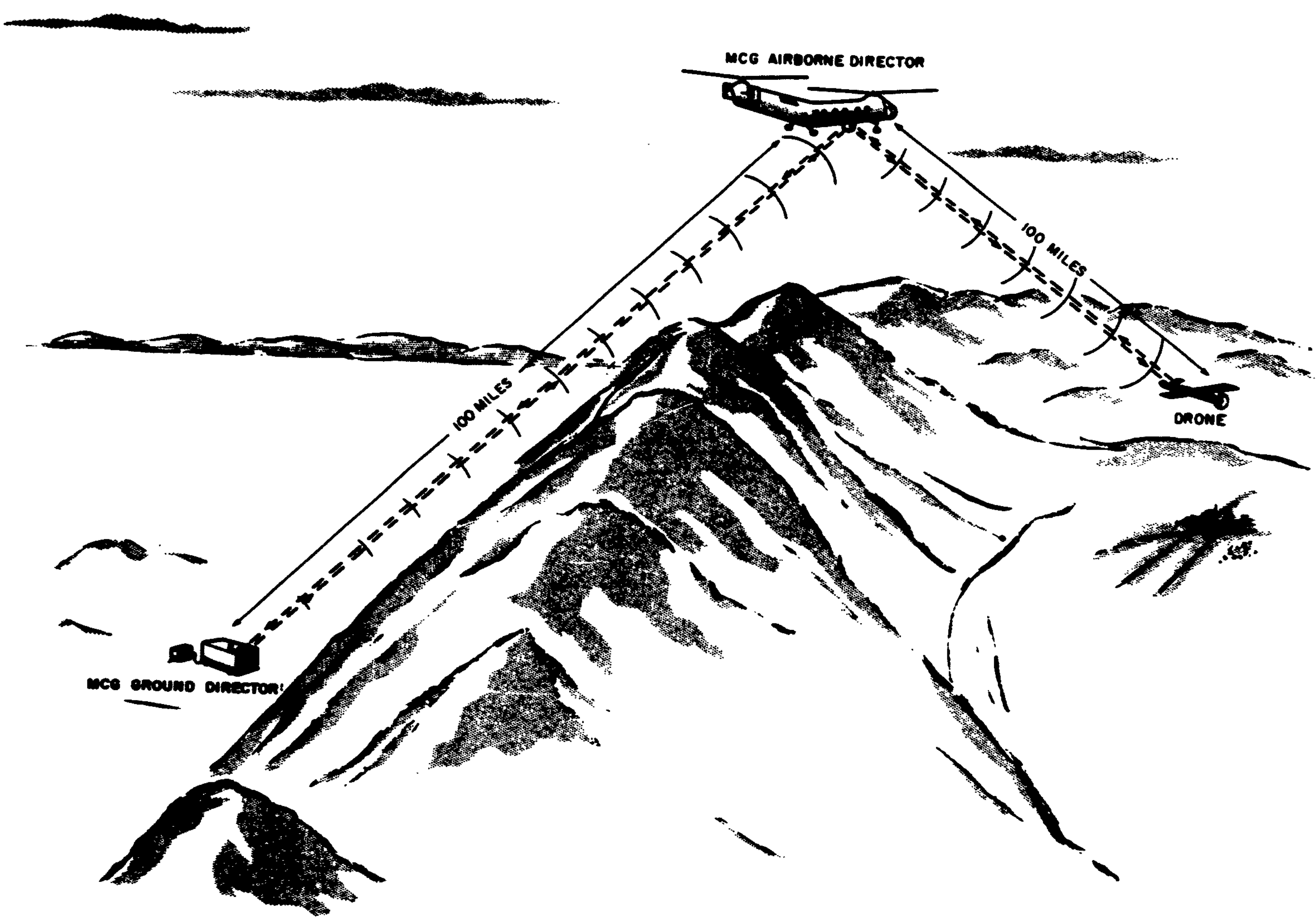


FIGURE 4-9 OVER-THE-HORIZON WITH HELICOPTER AS AIRBORNE DIRECTOR

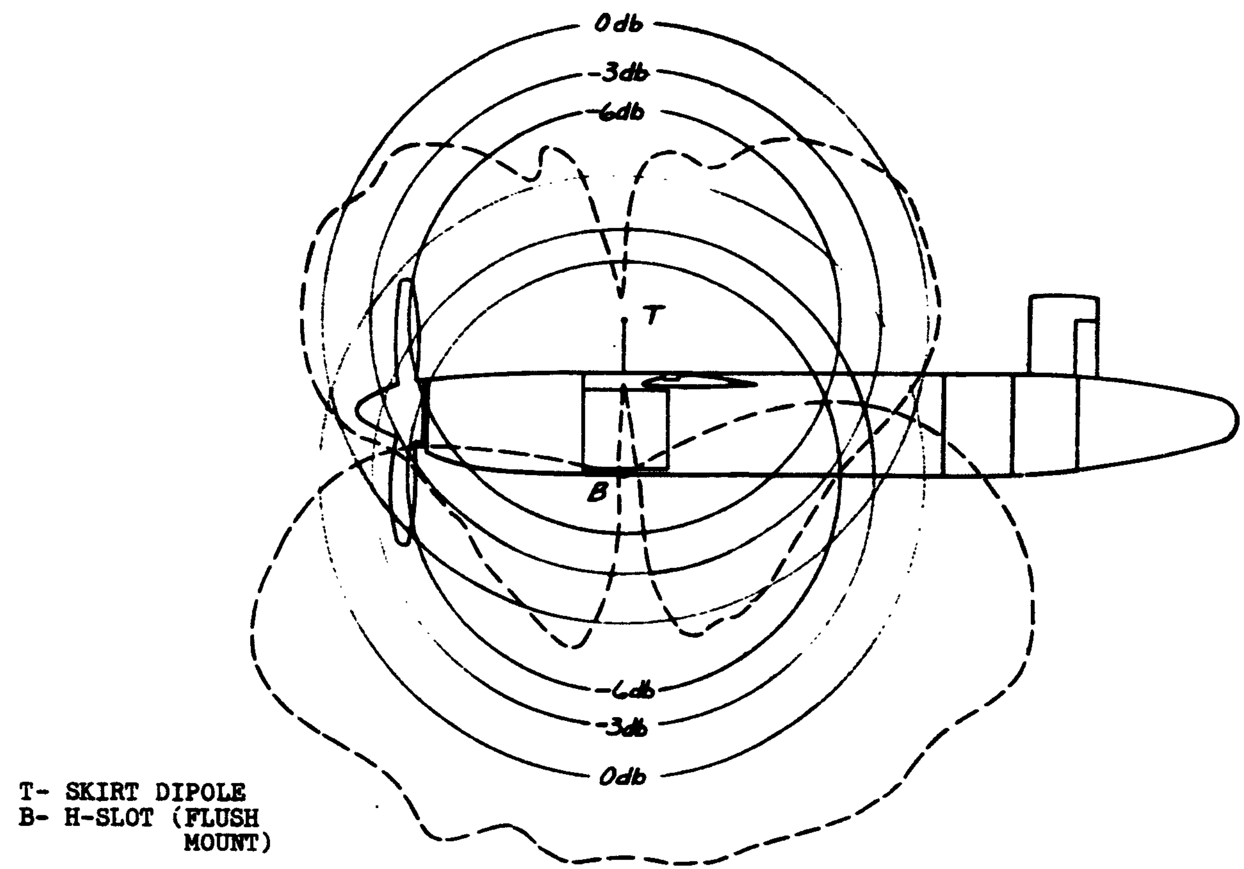
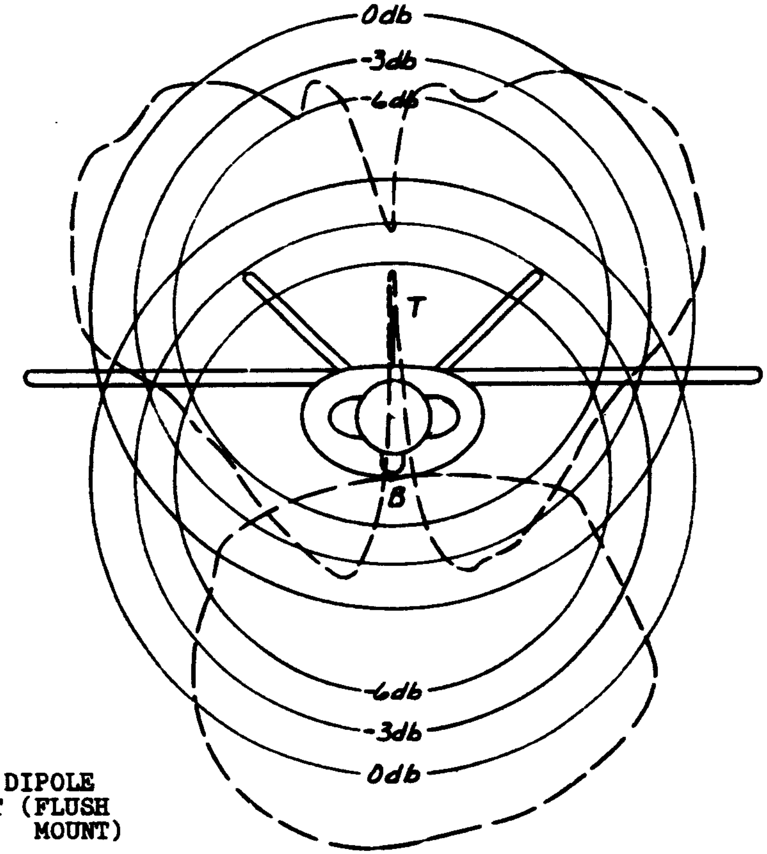


FIGURE 4-10 SD-2 ANTENNA PATTERN CONFIGURATIONS, SIDE VIEW



T- SKIRT DIPOLE
B- H-SLOT (FLUSH MOUNT)

FIGURE 4-11 SD-2 ANTENNA PATTERN CONFIGURATIONS, FRONT VIEW

are basically to acquire the vehicle at a range of 400 nautical miles as it enters an acquisition window 200 miles wide and 150,000 feet high. During the re-entry phase, it is planned to maintain radar control, perform energy management functions, and precision path control required to effect successful landings from the prescribed initial conditions.

The major elements required to meet this task are categorized into three groups: the airborne glider equipment, the landing site control station (figure 4-12), and the launch site test equipment which is depicted in figure 4-13.

The airborne glider elements are the data transponder and a flight coupler to link proportional command and control data to the basic stabilization systems of the glider. Automatic airspeed control and in-flight data transducing are also accomplished through this equipment.

The landing site control station, to be located at Edwards Air Force Base, is a modified ground director which will be located near the landing site runway and is the primary control point for the mission. Associated with the ground station are two portable control consoles which are planned to be utilized for remote heading and vertical path control during the final stages of glider flareout and landing. In order to ensure acquisition and control of the Edwards landing sight and to cover a potential abort situation due to line-of-sight propagation in which impact could occur in populated regions where the vehicle is out of sight of the ground director at Edwards, a second ground station with a 400-nautical mile range acquisition capability (not including the landing capability) is being planned for location at Point Arguello. This station will operate in a chain-station configuration with the station at Edwards. Its primary functions are: to provide the acquisition of 400 miles out from the west coast; to determine if the energy state of the glider is adequate to reach the Edwards landing strip and

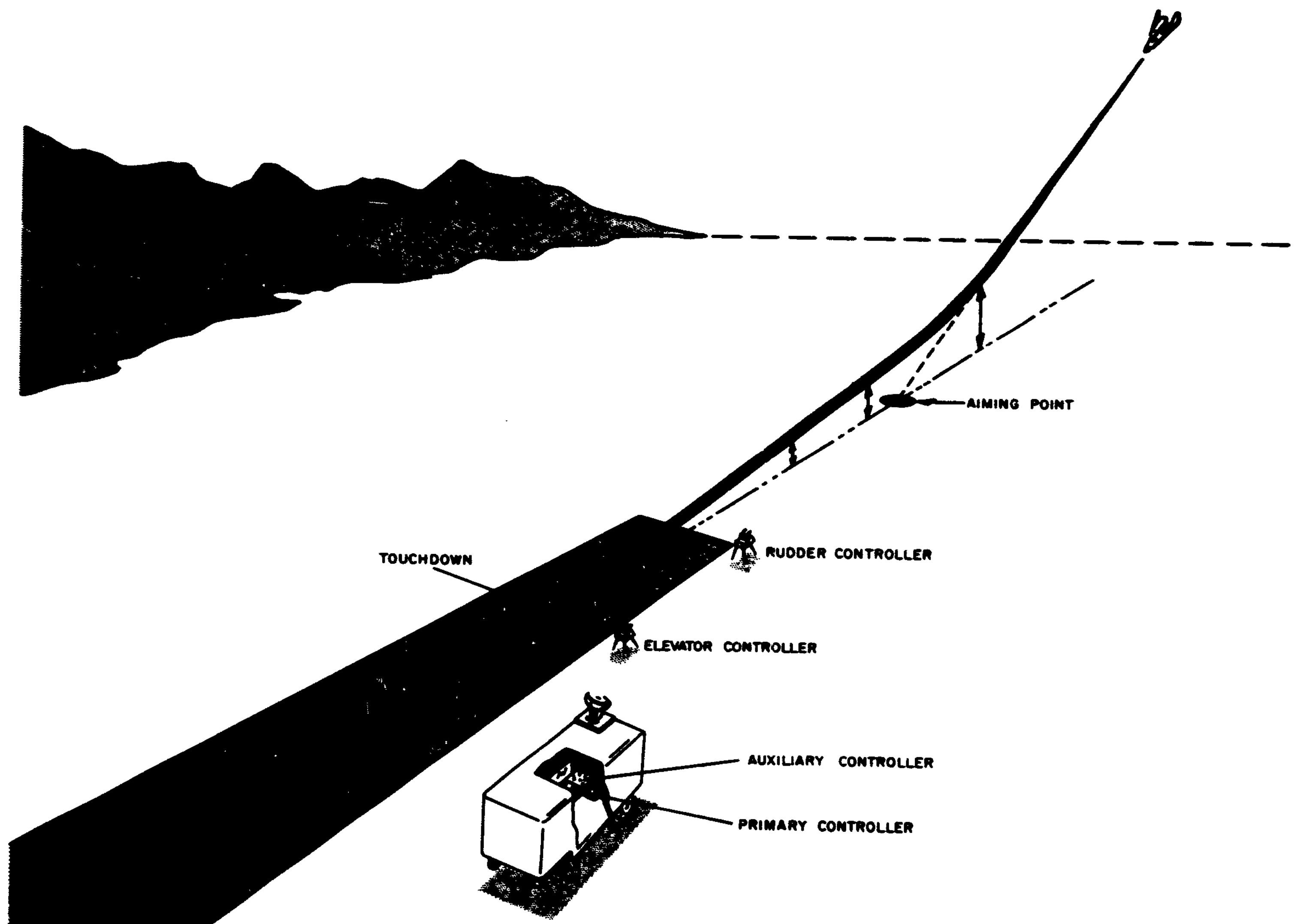


FIGURE 4-12 DYNA SOAR LANDING SITE CONTROL STATION

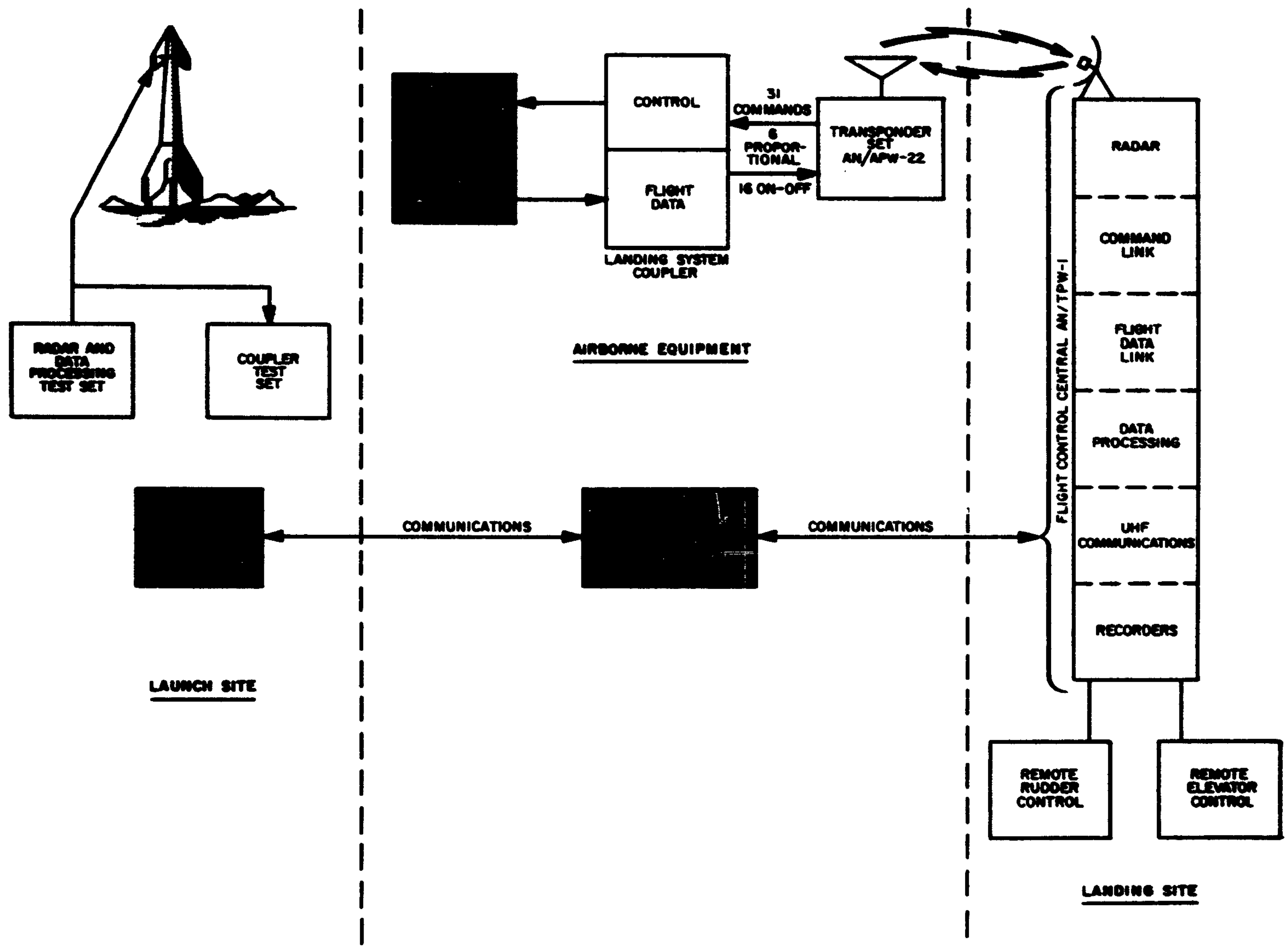


FIGURE 4—13 DYNA SOAR ELECTRONIC LANDING AND LAUNCH SITE BLOCK DIAGRAM

if not to command an abort maneuver to positively ensure its impact before reaching the coast; and if the energy state is adequate, to acknowledge controllability and assume control to perform initial guidance.

The launch site test equipment will consist of two test sets to perform the flight line checkout of the data transponder equipment and to check and calibrate the airborne coupler equipment. These sets will also simulate the command and data functions which are required to verify satisfactory landing system performance.

Primary control of the mission is performed by primary and auxiliary control operators located in the ground director. The function of these controllers is complemented by the radar operator and the two remote control operators previously mentioned. The primary tasks are as follows:

- Radar Operator - Sector scans the entry window, acquires the glider and establishes automatic track, and monitors performance after acquisition.

- Primary Operator - Is responsible for system engagement, auxiliary function controls, and control of the longitudinal flight path of the glider. This is accomplished by referencing longitudinal control data parameters which are displayed. These parameters include path deviation, altitude, angle of attack, pitch attitude, and airspeed.

- Auxiliary Operator - Is responsible for controlling the lateral path of the glider. His observations of status are obtained from a position plot, lateral path deviation, glider heading, bank angle, and turn indicators.

- **Remote Controllers** - Are responsible for extending landing skids and making the final longitudinal flare corrections just prior to touchdown, and for making heading and decrab corrections prior to touchdown.

When acquisition has been accomplished and re-entry is satisfactory, the vehicle would be controlled to arrive in the vicinity of the airfield at approximately 30,000 feet (figure 4-14) to allow for a straight-in approach. Only slight heading changes will be commanded for alignment purposes. Airspeed control equipment contained within the vehicle would automatically maintain a programmed airspeed through pitch attitude correction. Directional control on the runway would be maintained by a steerable nosewheel. Accuracies attainable with this system are 0.4 milliradian in angle and ±20 yards in range.

The antenna pattern characteristics for the Dyna Soar vehicle is one in which the major portion of the pattern faces forward. This is desirable since at greater ranges (15 to 400 nautical miles) the vehicle is facing toward the station. The forward portion of the pattern should cover a 90-degree conical area as shown in figure 4-15. This cone will permit course deviations of up to 45 degrees and to allow an angle of attack of ±45 degrees (assuming this to be sufficient). The pattern to the rear of the vehicle could be considerably below isotropic since the glider would be close to the landing site before maneuvers in excess of 45 degrees in heading are performed. In addition, an increase in the forward pattern gain can be realized if the rearward gain is reduced.

6. Booster and Capsule Recovery Application

Having gained considerable experience in radar tracking and command guidance, it was only natural to investigate possible applications in space systems. The first general area was discussed in the previous section with regard to the unmanned Dyna Soar glider vehicle's re-entry, recovery, and landing.

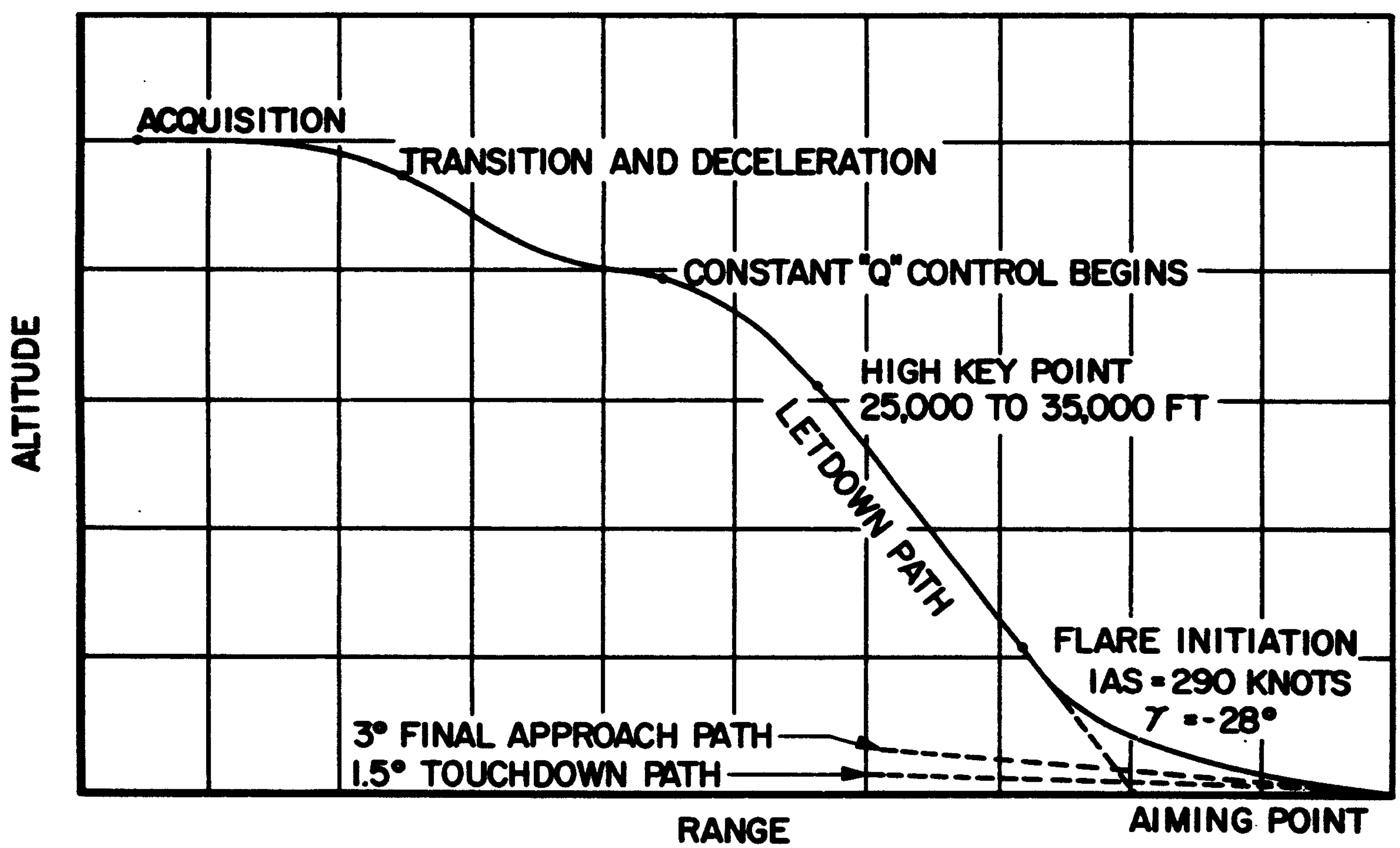


FIGURE 4-14 DYNA SOAR VERTICAL PATH PROFILE

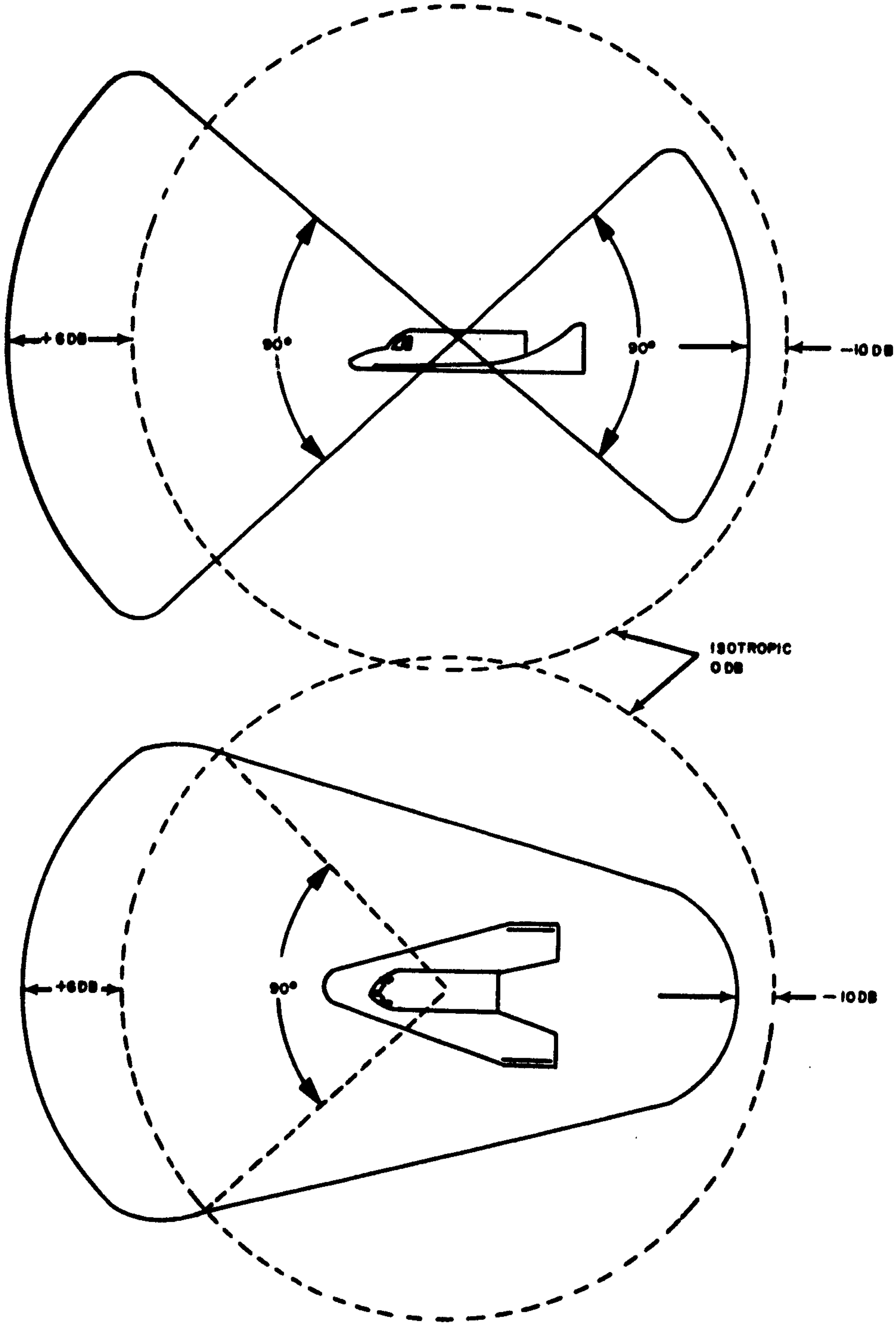


FIGURE 4-15 ANTENNA PATTERN CHARACTERISTICS

Further applications are possible with the manned parawing-equipped capsule and also the recoverable booster. Extensive studies conducted on this application resulted in rather firm system concepts. Basically, the system would be employed as an aid to the pilot during re-entry, but could provide complete and automatic ground control in an extreme emergency. A typical mission profile for recovery of a parawing-equipped capsule, as shown in figure 4-16, consists of three distinct phases:

1. Prior to parawing deployment
2. From parawing deployment (high key point) to start of straight-in approach (low key point)
3. From low key point to touchdown.

A ground computer continuously computes and transmits to a pilot's display the value of the equivalent airspeed he should fly in order to make good the low key point from the high key point, once the parawing is deployed. The ground computer accomplishes this by predicting the altitude of parawing deployment and, knowing the range required, can fairly accurately determine the required EAS to make good the low key point.

Once the wing is deployed, the pilot, using his standard airspeed indicator, attains and maintains the equivalent airspeed set on his display. He also continues to fly the bearing to low key as indicated on the panel. His range to go to low key has now been substituted for the previously displayed range to go to high key.

The ground computer establishes the lateral path which must be flown to expend the excess energy which will be present. When the parawing capsule has arrived at low key, the bearing signal is deactivated and a vertical and lateral path deviation indicator shows the pilot the necessary maneuvers to make to effect a successful letdown on the runway.

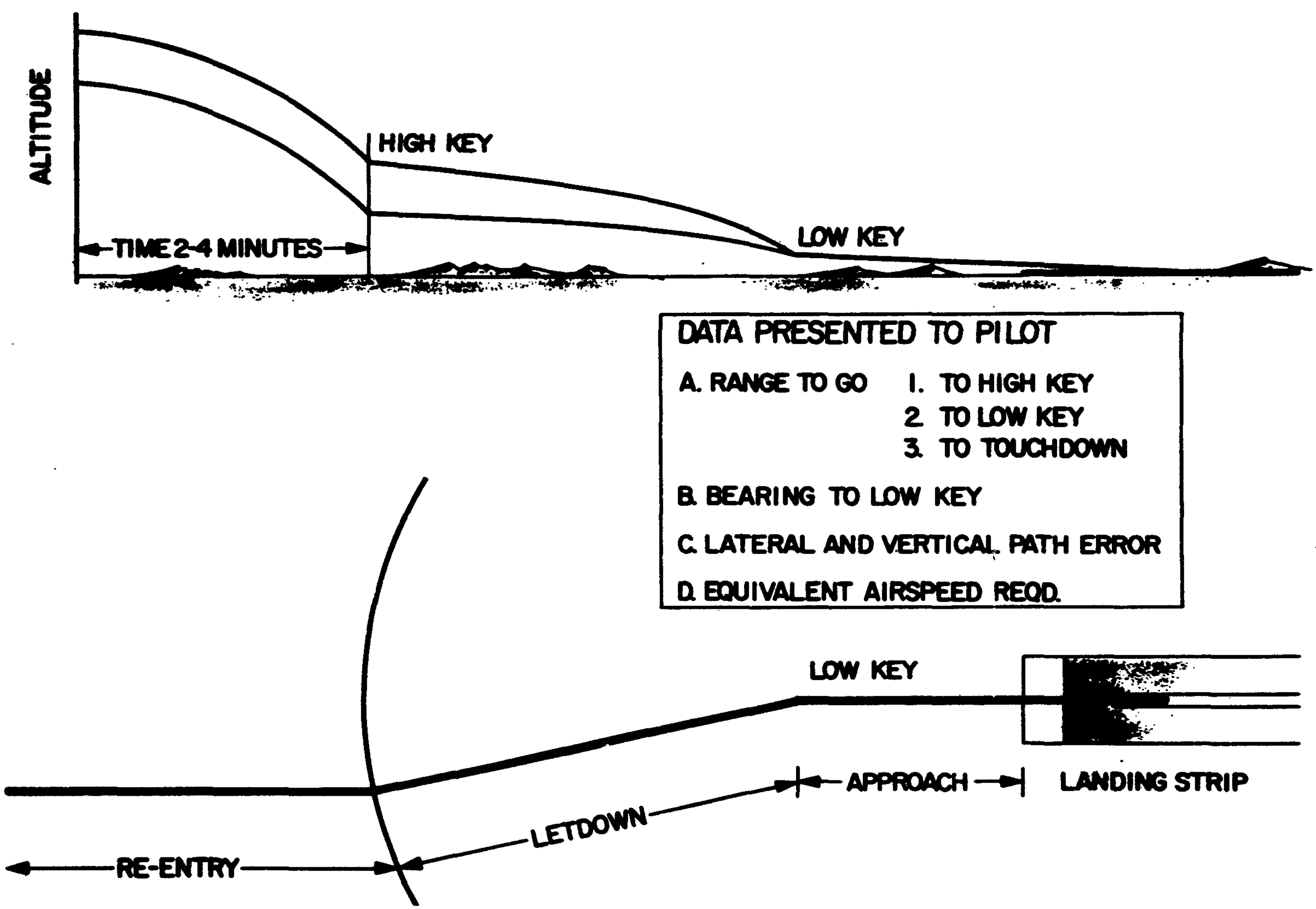


FIGURE 4-16 PARAWING EQUIPMENT CAPSULE LANDING PROFILE

In addition to the normal complement of tracking, guidance, control-and-display equipment, and conventional altimeter and airspeed indicator, the pilot will require a display of: (1) range to go to high key point, to low key point, and to touchdown; (2) bearing to low key point; (3) lateral and vertical path errors; and (4) equivalent airspeed required. Figure 4-17 shows a pilot's display for presenting these system parameters. Essentially, it is a standard HSI instrument modified to take indicated airspeed reference as a servo-driven input.

The application discussed for the parawing vehicle also readily applies to the recovery of boosters, whether they are powered or unpowered, winged or parawinged configurations. In a typical mission profile (figure 4-18), it is possible that radar line-of-sight limitations will necessitate the use of the airborne director relay mode of operation or the addition of an auxiliary ground director. In the case of a powered vehicle configuration, energy management, flareout, and landing are greatly simplified. In any event, the MCG System which includes the data transponder, the ground director, and the airborne director equipment is sufficiently versatile to apply to these particular applications. Sufficient information with regard to its performance has been previously sited and, therefore, is not reiterated.

7. Range Instrumentation Concepts

a. Southwest Recovery Complex

Studies have shown that the flight safety problem associated with recovery of space vehicles requires a method of (1) determining the vehicle's energy state early enough to assure that it can reach the terminal recovery area, or (2) controlling an abort maneuver. Since the low energy state represents the more severe problem and since under these conditions radar line-of-sight limits the range of the terminal recovery control center, an up range site is required.

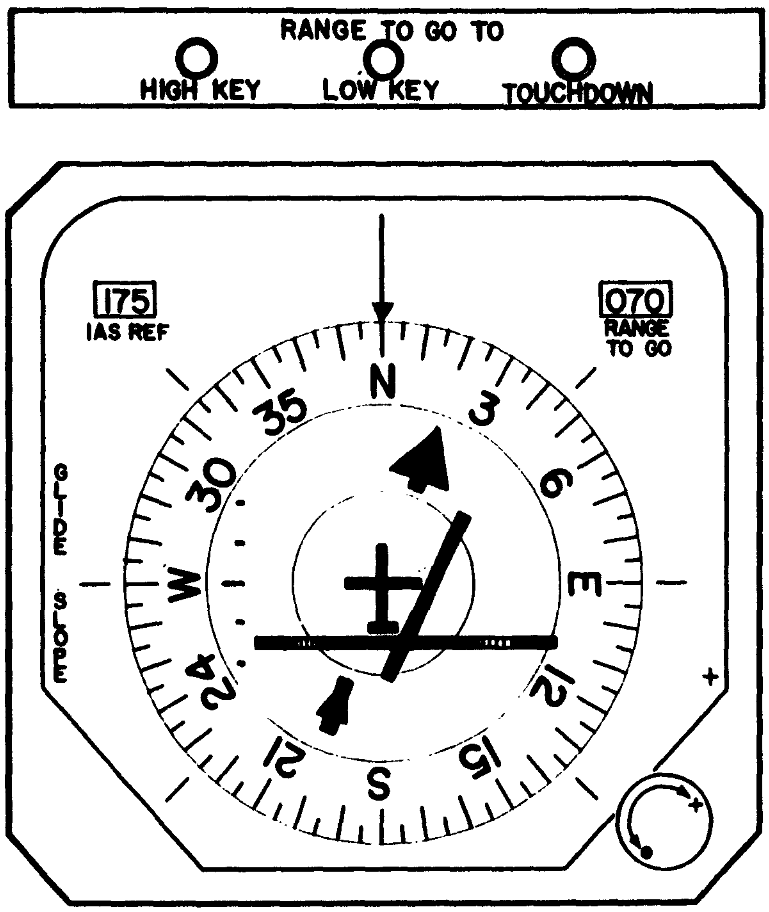


FIGURE 4-17 PILOT'S DISPLAY

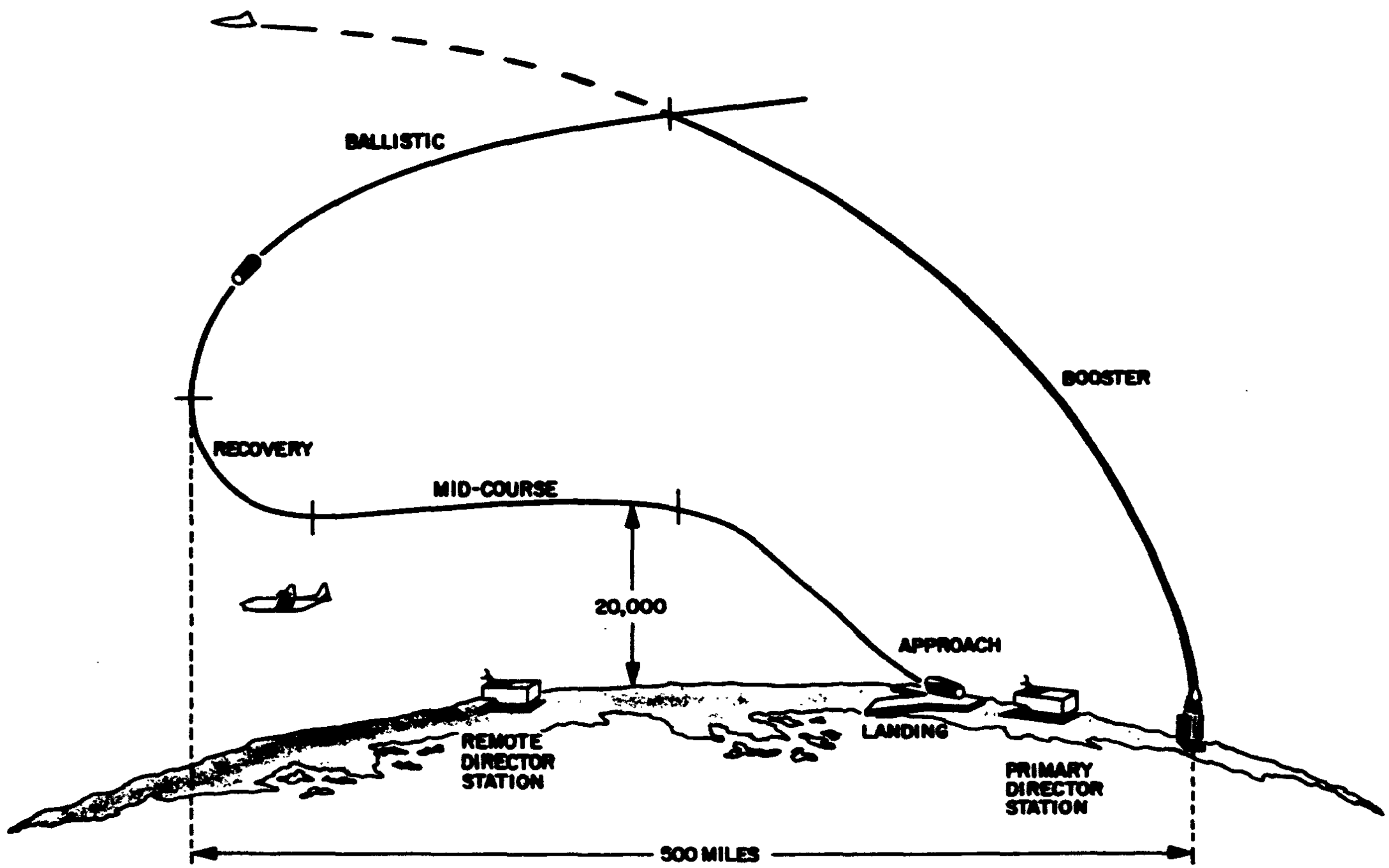


FIGURE 4-18 BOOSTER RECOVERY MISSION PROFILE

Considering the more common earth recovery trajectories and existing facilities, the Holloman Air Force Base, Edwards Air Force Base, and Wendover Air Force Base complex (figure 4-19) represents a suitable recovery complex. Such a complex provides a primary landing site and a secondary landing site for nearly any conceivable recovery trajectory.

The advantages of this recovery complex are:

- It provides alternate landing sites.
- Range instrumentation is already available.
- Corridor population density is very low.
- Weather conditions are good.
- Most of the land is Government owned or controlled.

The Dyna Soar System could easily be adapted to such a complex because capability to hand over control already exists in the system. Range extension to 500 miles by addition of larger antenna would provide greater desirable range coverage.

b. Location and Retrieval of Parachute Recovered Capsules

Studies have been performed to determine the optimum techniques and hardware to employ for tracking and positioning of parachute recovered capsules. In a particular study problem in which the impact area covered a rectangle 2000 nautical miles by 1000 nautical miles, it was determined that three to six JGC-130 type aircraft equipped with an airborne C-band tracking radar, 8 mc DF equipment, and accurate on-board navigation equipment would best perform the task of locating the impact point with a 3-mile square. (See figure 4-20.)

The JGC-130's would be placed on stations at 30,000 feet altitude so that their coverage areas overlapped adequately. Voice links between tracking aircraft and between aircraft and ground would be used to relay predicted impact and present position data.

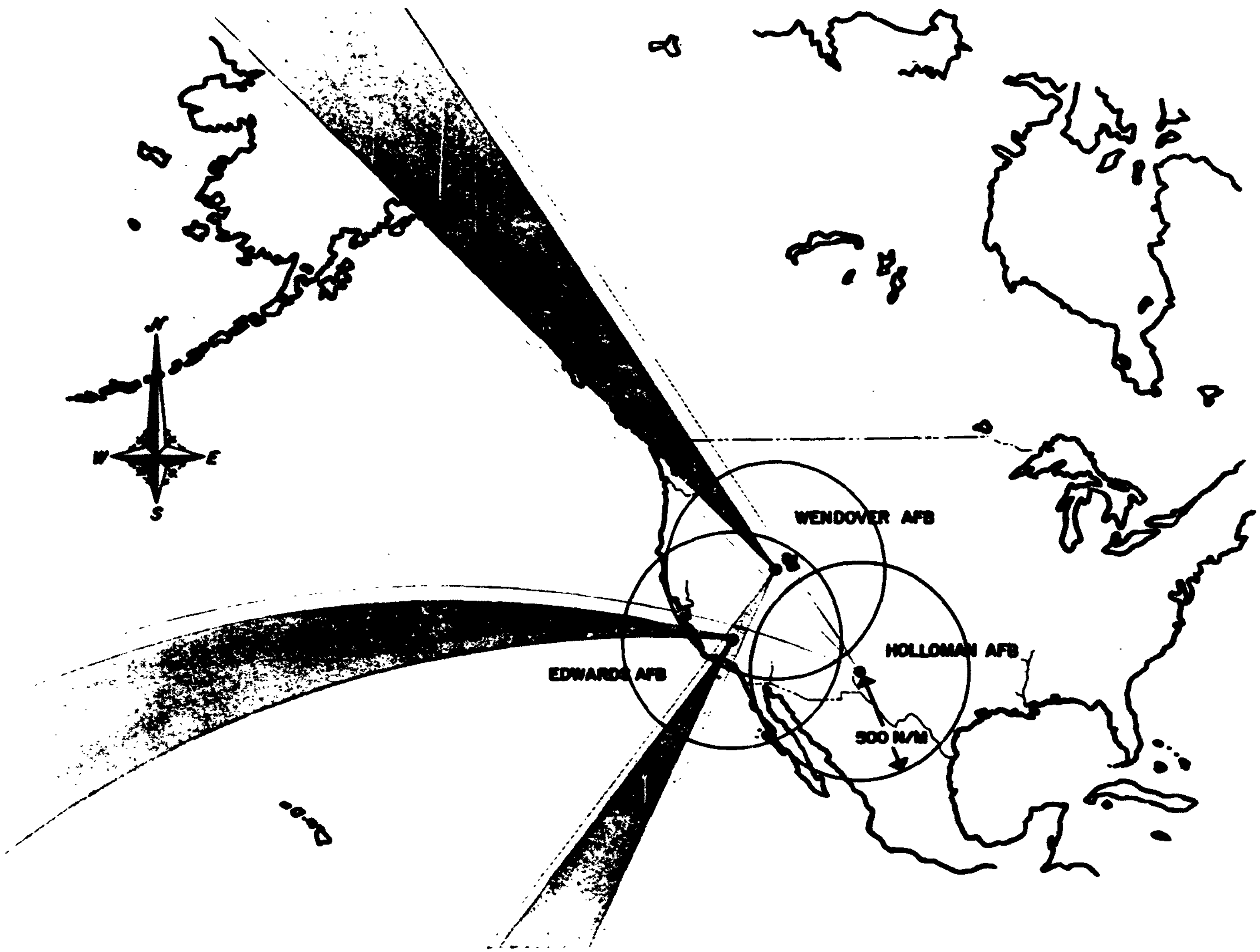


FIGURE 4—19 SUITABLE RECOVERY COMPLEX AND RECOVERY TRAJECTORIES

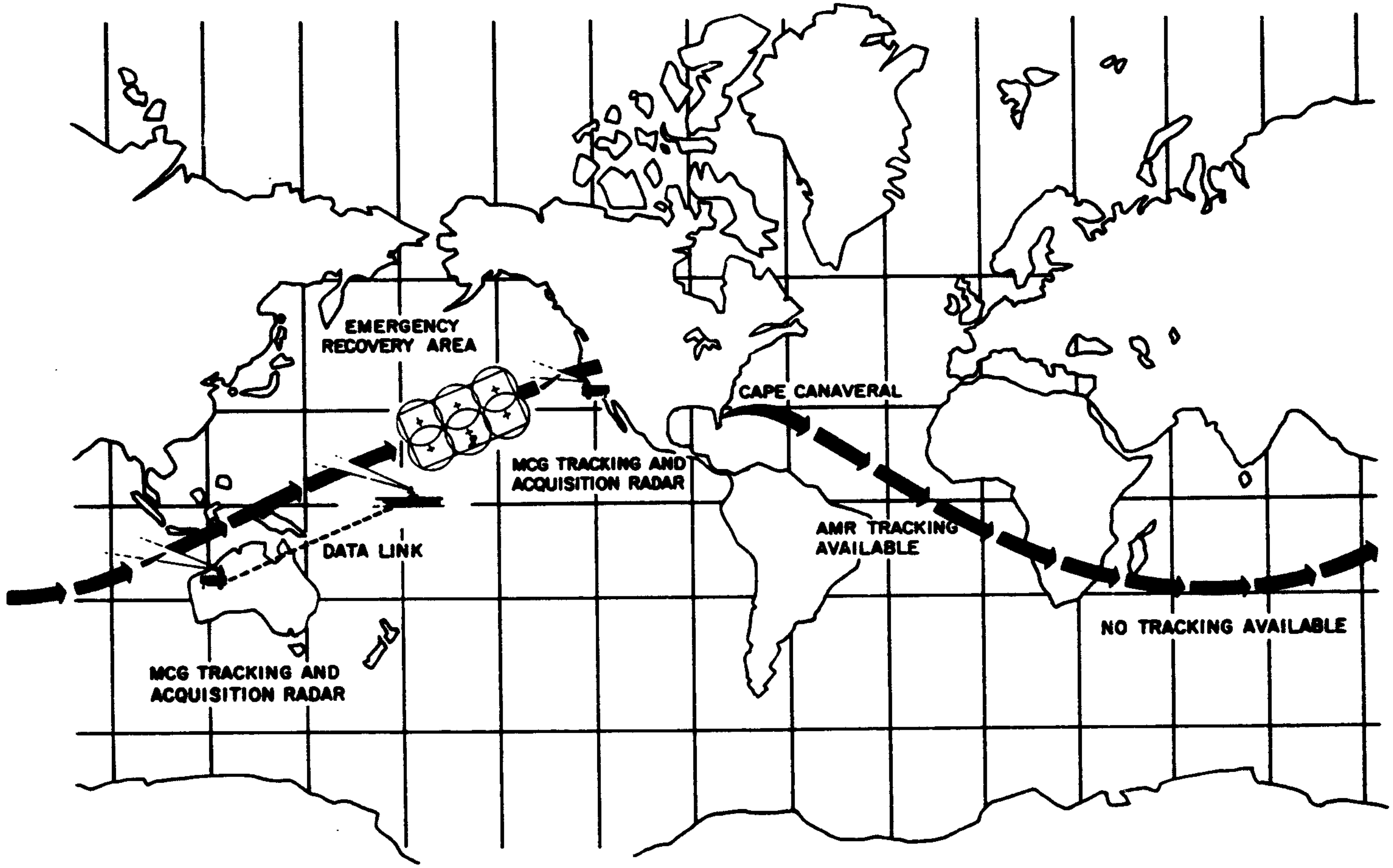


FIGURE 4—20 TRACKING AND POSITIONING PARACHUTE RECOVERED CAPSULES

In addition to the location and retrieval function, such an airborne station could be used as an acquisition aid for other instrumentation radars and could be used as a backup to the ground control center in the case of an abort or emergency recovery. In fact, such an abort maneuver or emergency recovery could be controlled from the ground control center through the airborne station if operated in the relay mode.

c. New and Advanced Techniques and Related System Concepts

Sperry has long recognized the inherent advantages of the potential in an integrated system such as is discussed for the MCG System. In addition to the study programs related primarily to vehicle recovery, the company has endeavored to improve system flexibility and capability by means of advanced techniques and hardware development. For instance, the company is presently funding development work on a new solid-state beacon. This beacon has a modular design to provide any or all of the functions of interrogation (range and tracking), command, and data return. With a capability equal to or exceeding the present MCG transponder, the solid-state beacon would weigh only 18 pounds and occupy a volume of 325 cubic inches. Such a beacon is absolutely necessary for most space vehicle applications where size and weight requirements are at a premium.

Another area of investigation that is believed to be very promising is the use of both continuous wave (CW) and pulsed carrier transmission over a common link using common antennas. The primary function of the CW carrier transmission would be to provide an additional data link particularly suitable for voice transmission as well as other forms of information. By applying phase-lock techniques to the CW transmission, it is possible to extract Doppler frequency information for more accurate velocity and acceleration measurement. Range data would continue to be derived from the more convenient pulsed

carrier transmission. Furthermore, the use of pulsed carrier is advantageous where acquisition problems associated with phase-lock techniques are an important consideration. In addition, pulse carrier transmission is suited to burst transmission techniques suitable to certain system applications. Optimum utilization of the CW power source would be accomplished by using this source as the local oscillator (LO) for the pulsed carrier transmission.

d. Space Station/Space Vehicle Rendezvous

The added system capability obtained using the combined CW/pulse technique previously described is particularly applicable to the mission requirements for the rendezvous of a space vehicle at a space station, as shown in figure 4-21. Accurate velocity and acceleration data coupled with voice communications would facilitate "docking" the space vehicle to the space station. The control station would be a simplified and miniaturized version of the present MCG System.

Essentially the same system could be employed for station keeping between two space vehicles or satellites.

e. Synchronous Satellite Application

The system capabilities previously discussed are particularly applicable to maintaining the correct position of a synchronous satellite. In the proposed configuration of figure 4-22, the ground control station consists of a fixed conical scan antenna monitoring the satellite for positional error information in order to transmit the appropriate command to correct the satellite position in case of error. The satellite antenna reflector is an integral part of the satellite shape. The approximate 22,000-mile range for a synchronous satellite is obtained by increasing the ground station some 10 db and using a 30 db (30-inch) satellite antenna. The directive antenna configuration would provide security to the transmission link.

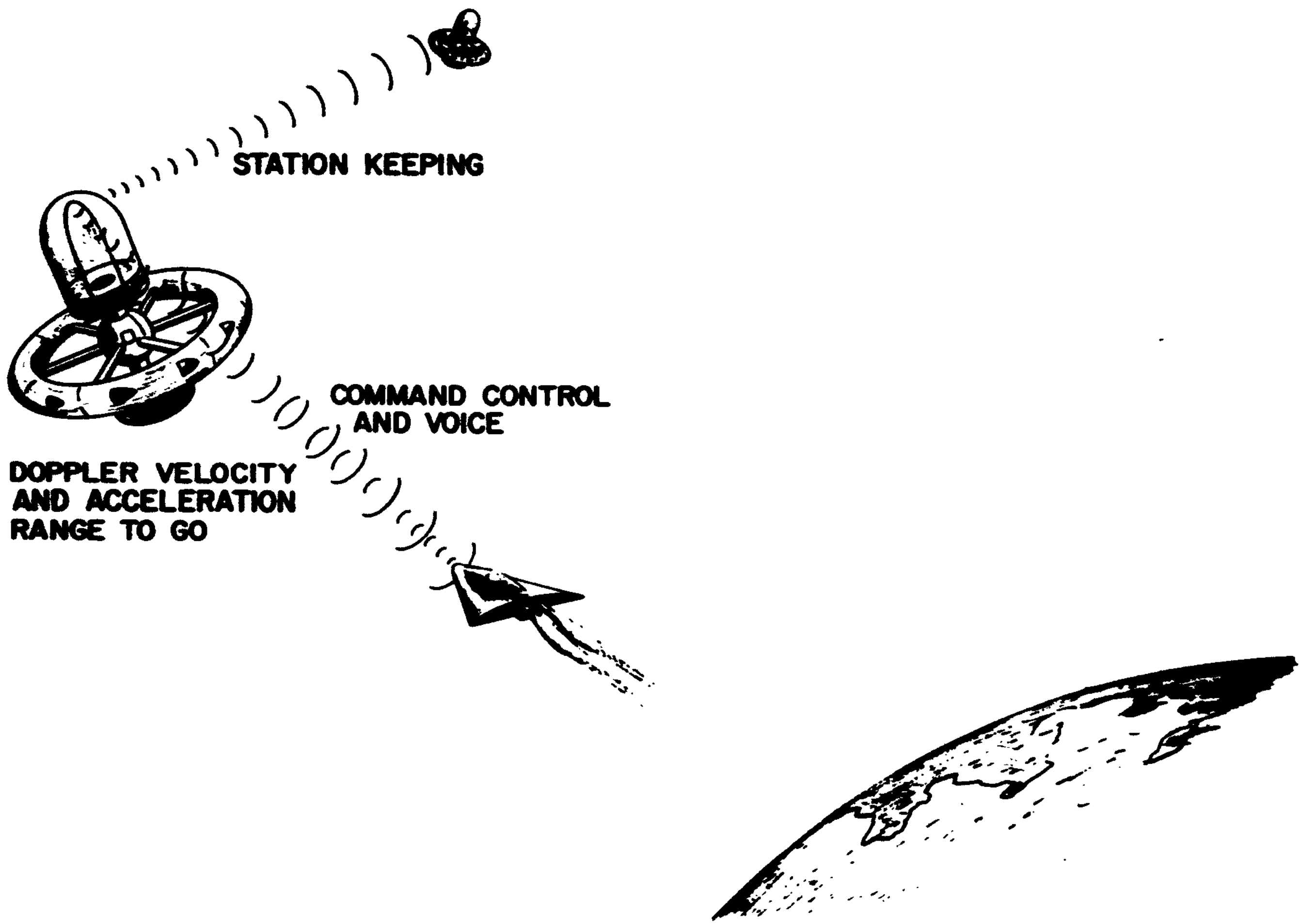


FIGURE 4—21 SPACE STATION RENDEZVOUS

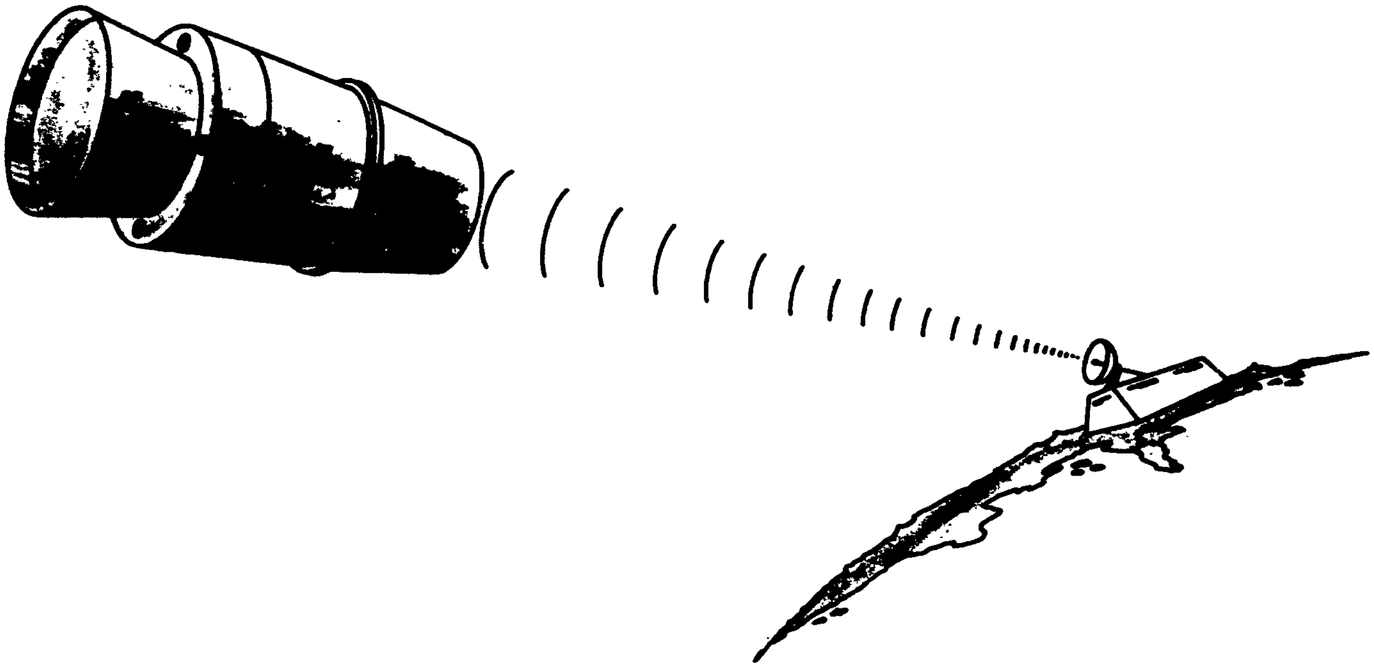


FIGURE 4—22 SYNCHRONOUS SATELLITE STATION KEEPING

SECTION V

SUPPORTING CHARACTERISTICS

SECTION V

SUPPORTING CHARACTERISTICS

A. SYSTEM SPECIFICATIONS

The system characteristics of primary concern have been described throughout the previous sections. Additional characteristics for the major elements of the system are presented in a table of specifications. These are shown in tables 5-1, 5-2, and 5-3 which list the specifications for the ground director while tables 5-4, 5-5, and 5-6 list the specific characteristics for the airborne director and the data transponder. These specifications cover the existing system characteristics.

B. ANTENNA COVERAGE

In order for MCG to meet mission requirements, an appropriate antenna system had to be designed. All major factors controlling the system design are contained in the equipment. The various tracking rates, slewing rates, and coverage capabilities have been cited in previous sections without having shown the specific pattern characteristics. These characteristics are shown in figures 5-1 and 5-2 for the ground director and the airborne director, respectively.

The drone vehicle antenna coverage requirements are dependent upon the mission requirements which define the degree of coverage and polarization requirements. Previous and present MCG operations have used linear antennas on the QF-80 and XQ-2C drones and circular polarized antennas on the QB-47.

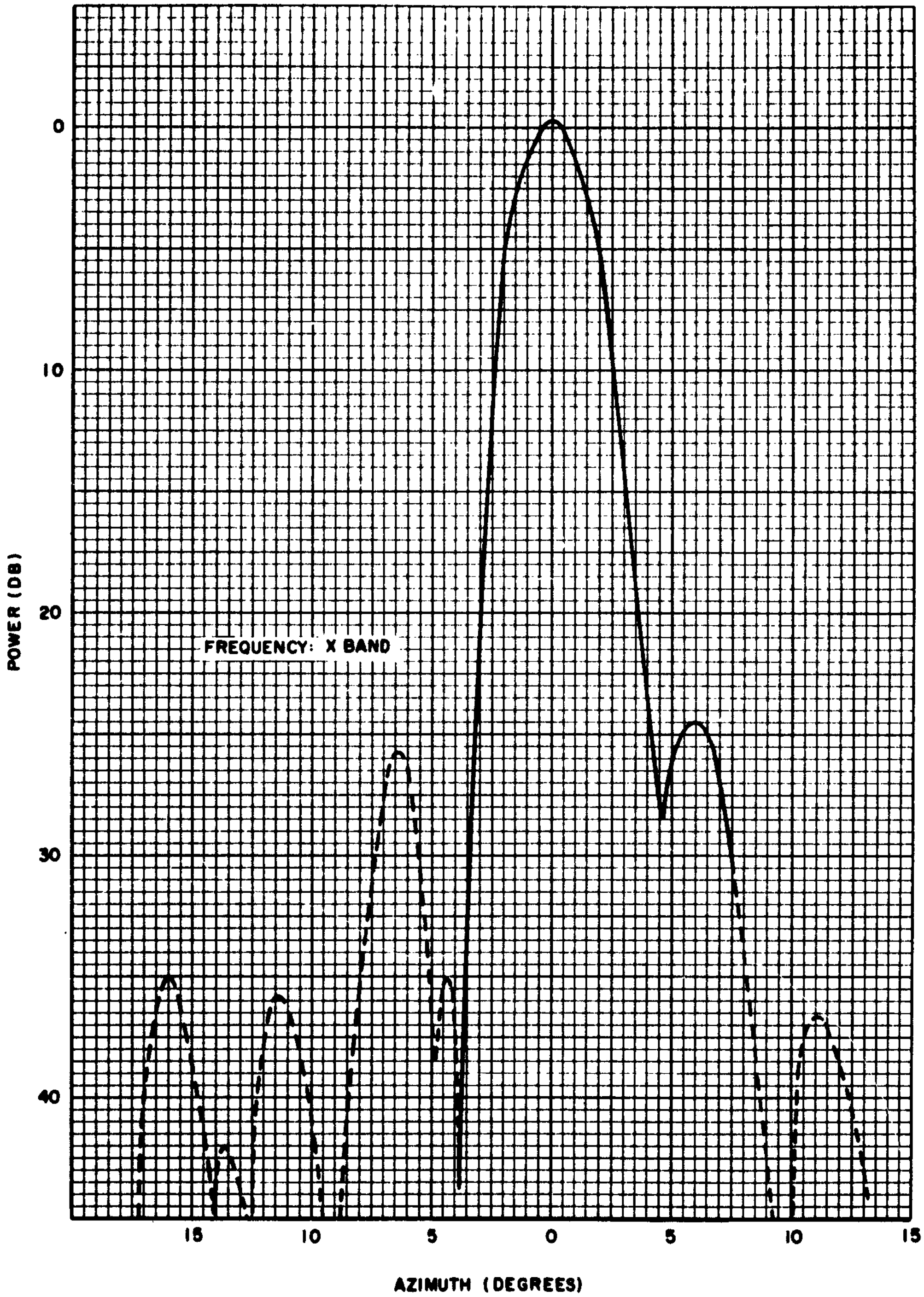


FIGURE 5-1 FLIGHT CONTROL CENTRAL AN/TPW-1 (GROUND DIRECTOR) ANTENNA PATTERN

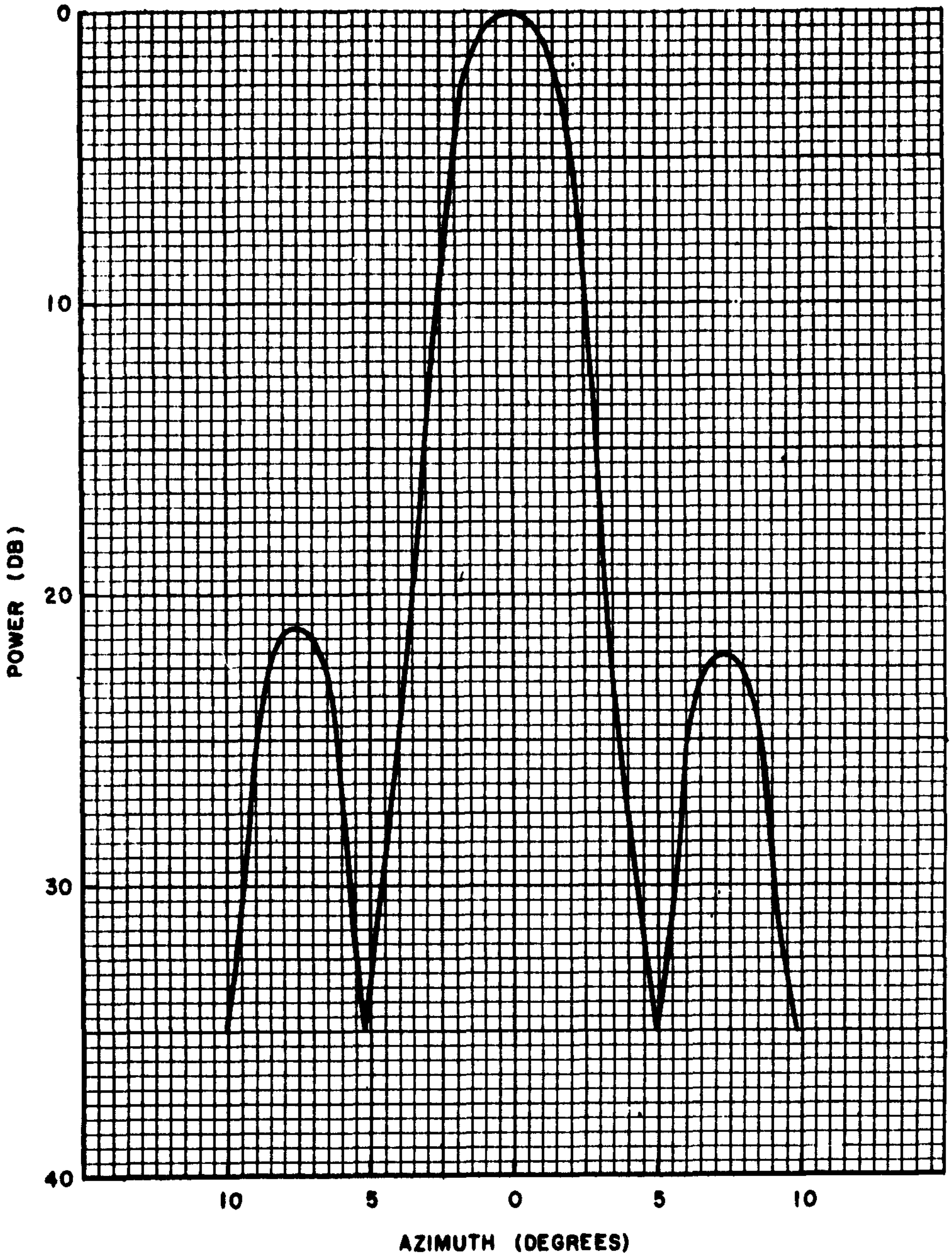


FIGURE 5-2 COMMAND GUIDANCE INTERROGATOR SET AN/APW-23(XY-1)(AIR DIRECTOR) FREE SPACE ANTENNA PATTERN

Figure 5-3 presents the linear antennas pattern for the skirted dipole antenna used on the XQ-2C. It represents the free space characteristics obtained through actual measurement with the antenna mounted on the XQ-2C tailcup. The QF-80 contained a single linearly polarized skirted dipole antenna which had similar pattern characteristics. The antenna was mounted on top of the vehicle's nose section.

A circular polarized antenna system is used on the QB-47. The QB-47 antenna has a pattern characteristic consistent with the coverage required, and being circularly polarized, it affords a 3 db improvement in gain. Figure 5-4 presents the azimuth characteristics (for a horizontal cut) of the antenna receiving circular polarized inputs. Vehicle coverage available using these antennas is shown in figures 5-5 and 5-6 which are the front and side view characteristics.

TABLE 5-1

CURRENT GROUND DIRECTOR

ANTENNA SPECIFICATIONS

Item	Characteristics
Parabola diameter	32 inches
Antenna gain	34 db
Antenna beam width (3 db points)	2.7 degrees, nominal
Side lobe power	24.5 db down
Polarization	Circular
VSWR (including rotary joints)	1.25
Power handling capability	10 kw peak
Nutation rate	60 revolutions per second
Nutation conical scan	2 degrees
Rotation in azimuth	360 degrees

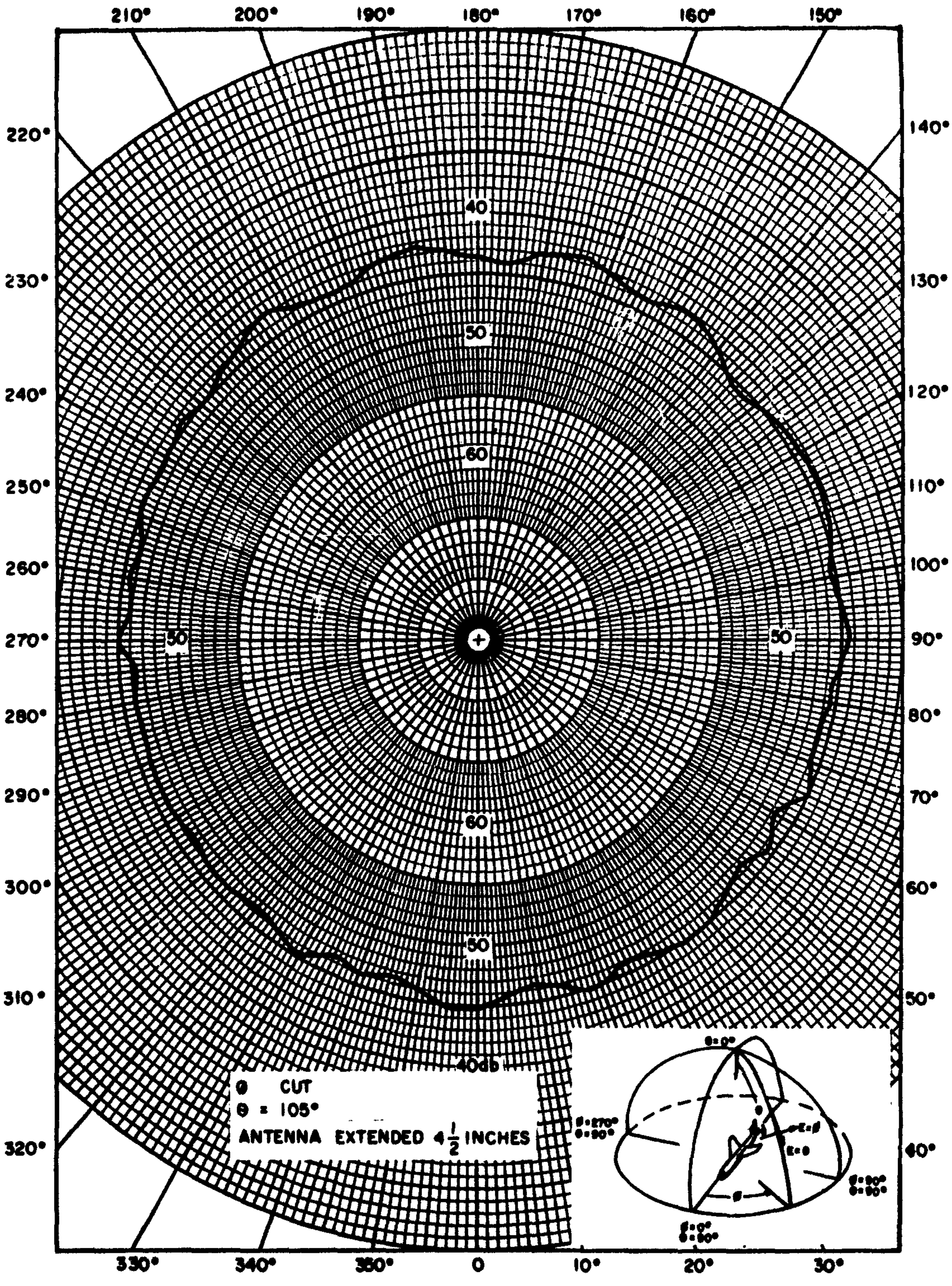


FIGURE 5-3 SKIRTED DIPOLE ANTENNA PATTERN

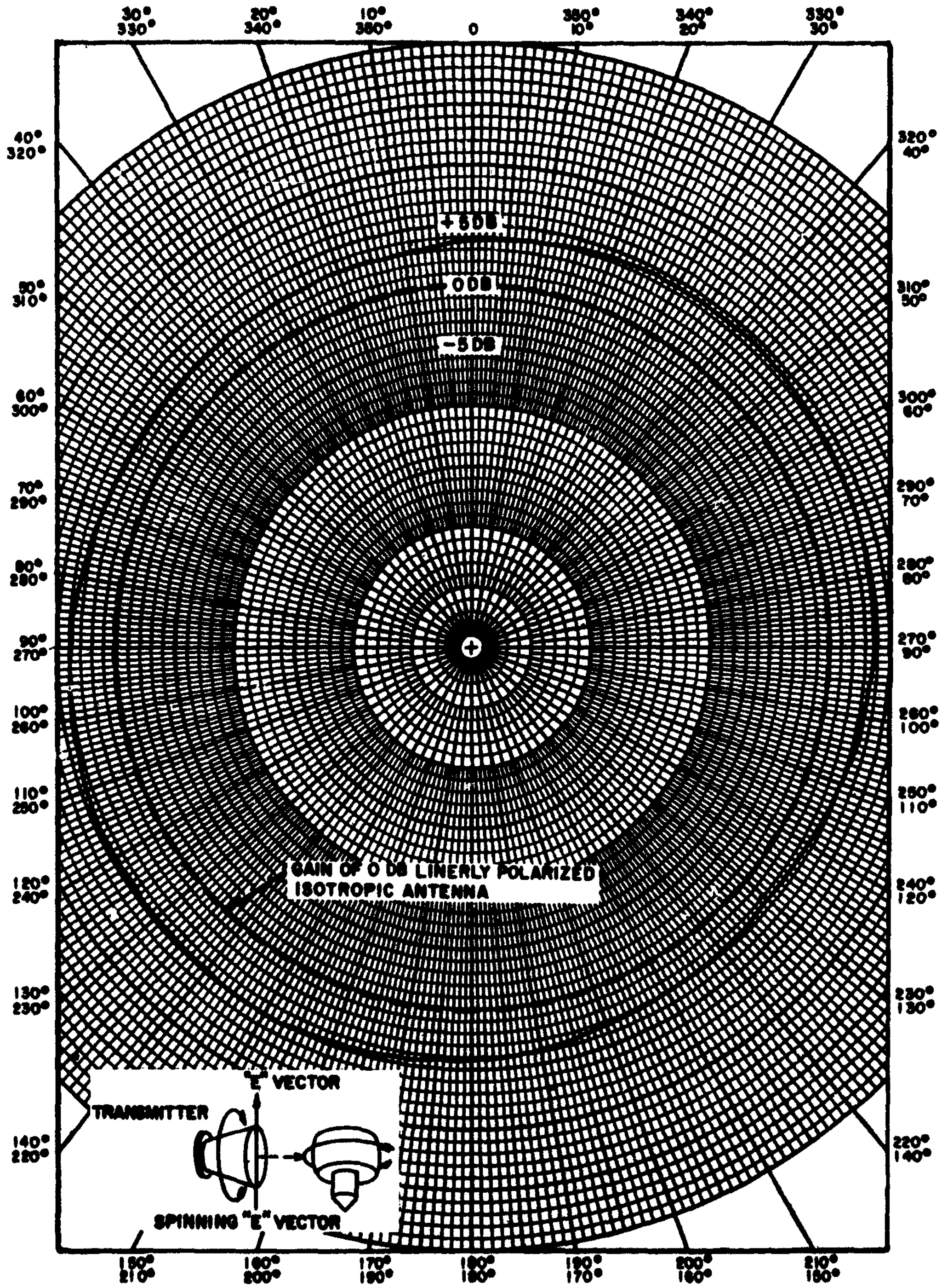


FIGURE 5-4 HORIZONTAL CUT PATTERN FOR QB-47 ANTENNA RECEIVING CIRCULARLY POLARIZED SIGNAL

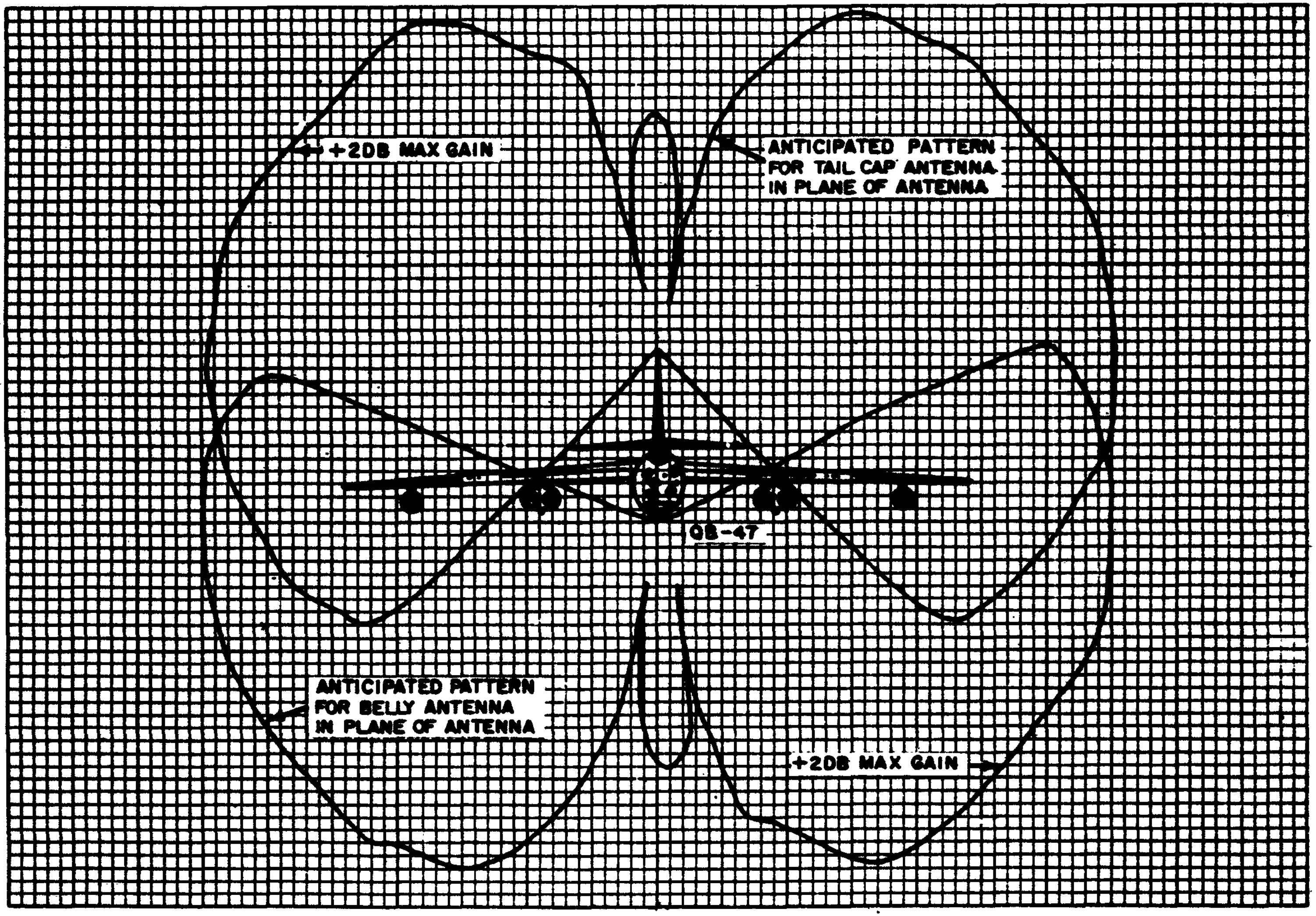


FIGURE 5-5 FRONT VIEW, COMPOSITE ANTENNA PATTERN

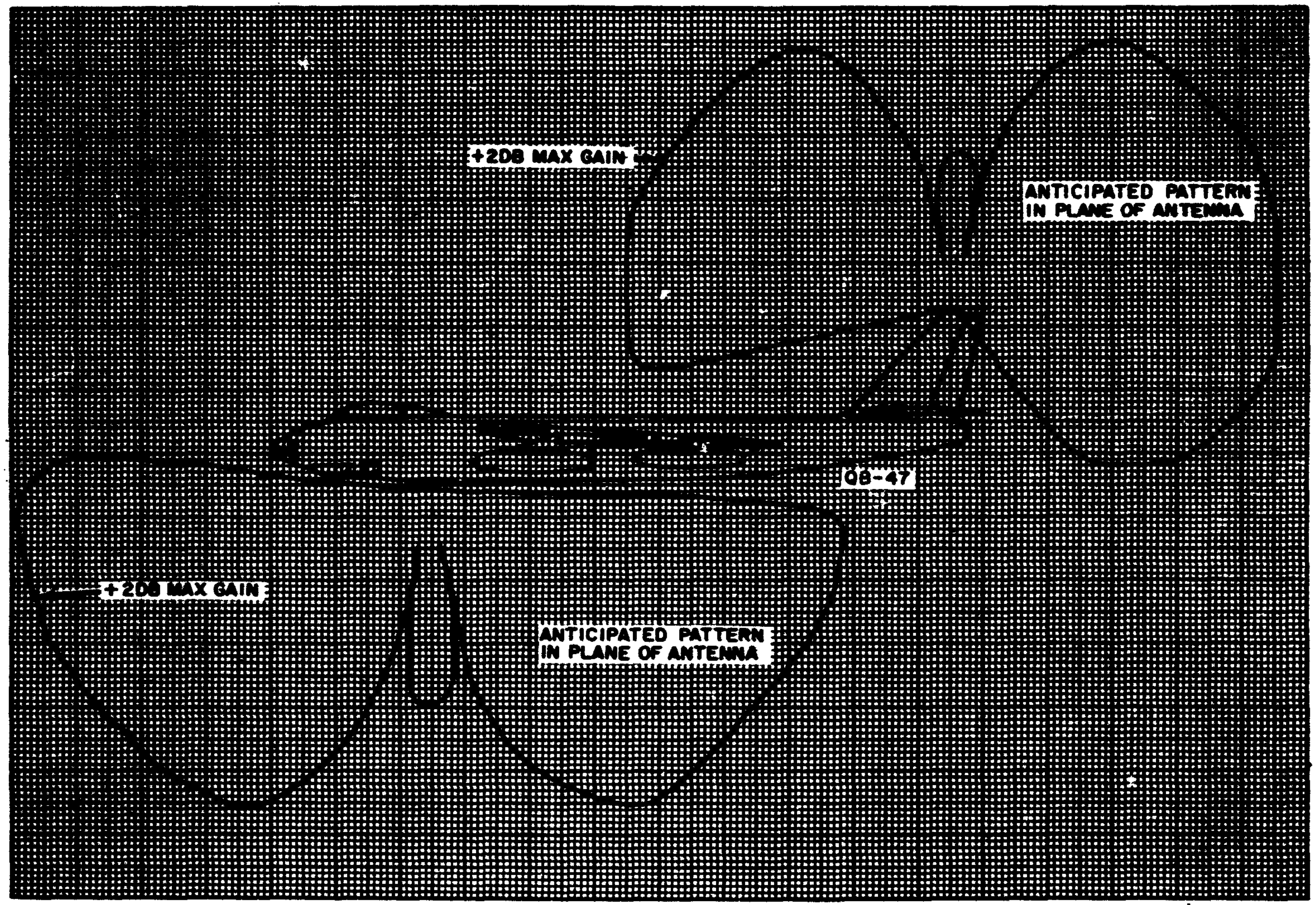


FIGURE 5-6 SIDE VIEW, COMPOSITE ANTENNA PATTERN

TABLE 5-1 (cont)

CURRENT GROUND DIRECTOR

ANTENNA SPECIFICATIONS

Item	Characteristics
Azimuth slewing rate	6 rpm
Azimuth tracking rate (maximum)	15 degrees per second
Elevation scan	-5 degrees to +88 degrees
Elevation slewing rate	15 degrees per second
Elevation tracking rate (maximum)	12 degrees per second

TABLE 5-2

GROUND DIRECTOR TRANSMITTING

AND RECEIVING CHARACTERISTICS

Transmitting Characteristics	
Power	5 kw minimum pulse power
Frequency	f_t ±2.5 mc (X-Band)
Receiving Characteristics	
Sensitivity	-85 dbm
Center frequency (rf)	f_r ±2.5 mc (X-Band)
Center frequency (i-f)	45 mc
I-F bandwidth	13 mc (3 db points)
Video bandwidth	500 kc

TABLE 5-3

GROUND DIRECTOR RANGE

AND TRACKING CHARACTERISTICS

Item	Characteristics
Minimum range	75 feet to target vehicle
Maximum range	200+ nautical miles to target vehicle
Plot accuracy (system)	1.37 yards per nautical mile
Tracking accuracy	20 yards rms in range 1 milliradian rms, nominal, in azimuth and elevation

TABLE 5-4

AIRBORNE DIRECTOR

ANTENNA SPECIFICATIONS

Items	Characteristics
Parabolic diameter	24 inches
Angular displacement in azimuth	360 degrees
Angular displacement in elevation	+40 degrees (above horizon) to -85 degrees (below horizon)
Azimuth slewing rate	6.0 ± 1.5 rpm
Azimuth tracking rate (maximum)	15 degrees per second
Elevation slewing rate	15 degrees per second
Elevation tracking rate (maximum)	12 degrees per second
Antenna beam width (3 db point)	4 degrees
Antenna gain	32.5 db

TABLE 5-4 (cont)

AIRBORNE DIRECTOR

ANTENNA SPECIFICATIONS

Items	Characteristics
Nutation rate	30 rps
Polarization	Circular to the right
VSWR	1.5 (maximum)
R-F power handling capability	10 kw (peak)
Side lob power	22 db below maximum

TABLE 5-5

AIRBORNE DIRECTOR AND

DATA TRANSPONDER TRANSMITTING

AND RECEIVING CHARACTERISTICS

Transmitting		
Item	Airborne Director Section	Data Transponder Section
Power	5 kw peak pulse power	1 kw peak pulse power
Frequency	$f_t \pm 2.5$ mc (X-Band)	$f_t \pm 2.5$ mc (X-Band)

TABLE 5-5 (cont)

AIRBORNE DIRECTOR AND DATA TRANSPONDER

TRANSMITTING AND RECEIVING CHARACTERISTICS

Receiving		
Item	Airborne Director Section	Data Transponder Section
Sensitivity	-85 dbm	-80 dbm
Frequency	f_r ±2.5 mc (X-Band)	f_r ±2.5 mc (X-Band)
I-F frequency	45 mc	45 mc
I-F bandwidth	13 mc	7 mc
Video bandwidth	500 kc	500 kc

TABLE 5-6

AIRBORNE DIRECTOR AND DATA TRANSPONDER

RANGE AND TRACKING CHARACTERISTICS

Item	Characteristics
Minimum range	75 feet to unmanned vehicle (drone)
Maximum range	200+ nautical miles to unmanned vehicle
Drone position plotting accuracy at maximum range	1670 yards (maximum)
Air director position plotting accuracy	1030 yards (maximum)

C. FREQUENCY CONTROL

Frequency stability is one of the prime considerations of the director stations and the drone data transponder. The director station interrogators have motor-tuned magnetrons and voltage-tuned local oscillators operating from a common frequency control system, otherwise known as an AFC system. This system contains two reference cavities. The frequency of one cavity is designed above the desired command magnetron and local oscillator frequencies, and the other is designed below. Small portions of the magnetron and local oscillator outputs are fed into the AFC cavities, whose outputs are detected and filtered. The magnetron-generated portion of the detected AFC signal is a pulse while the local oscillator portion is a steady-state d-c signal. This difference allows the error signal for the two corrective loops to be separated. The pulse outputs are used to drive the magnetron tuning motor until the pulse signal output is nulled. Local oscillator frequency is corrected by means of a d-c voltage which is applied and fed to a reflex klystron reflector. There are also separate sweeps for both the magnetron and local oscillators to bring the frequency within the sensitivity range of the reference cavities. Use of temperature-stabilized nickel alloy reference cavities, whose frequency is known precisely, permits this type of frequency control to be accurate and stable.

Due to the minimum space available in drones, it is necessary to keep the data transponder frequency-control design simple and effective. The local oscillator in the data transponder is stabilized by means of a Stalo cavity. The magnetron frequency stability is aided by means of a ferrite load isolator which limits load changes from affecting the magnetron. The magnetron that is used is temperature-compensated to minimize frequency deviations. To allow for possible airborne frequency deviations, a frequency drift indicator was designed into the

director rotation equipment. Freedom to shift the received frequency reference by ±6 mc was provided. After many hours of operation this frequency shift has never been needed and is currently considered unnecessary.

D. INTERFERENCE CONSIDERATIONS

To ensure reliable data transmission under all circumstances, the pulse-code type modulation system is employed. This type of modulation is relatively insensitive to noise, to incidental frequency deviations, to amplitude variations, and to changes in pulse duration. Identity decoding schemes were employed to further ensure that only the desired message would be decoded by the system. Desired codes for reception are preset in the data transponder and in both of the director stations, prior to mission operations. Such a scheme requires multiple coincidence decoding in the receivers of the major elements. This is accomplished through using tap delay lines, of a matched filter-type, which provide inherent discrimination against pulse-type jamming as well as random noise. Microwave bandpass filters are also employed in the drone and the director systems to reject image frequency interference and strong signals containing all frequencies. Actual laboratory and field test measurements were made to determine the degree of susceptibility of the equipments in question. Curves 1 through 4 in figure 5-7 are plots of the radar range equation for the MCG System with equipments having the following parameters:

TPW-1 power	+67 dbm
APW-22 power	+60 dbm
TPW-1 antenna gain	+30 db
APW-22 antenna gain	0 db
System losses	-30 db
Atmospheric losses	Omitted

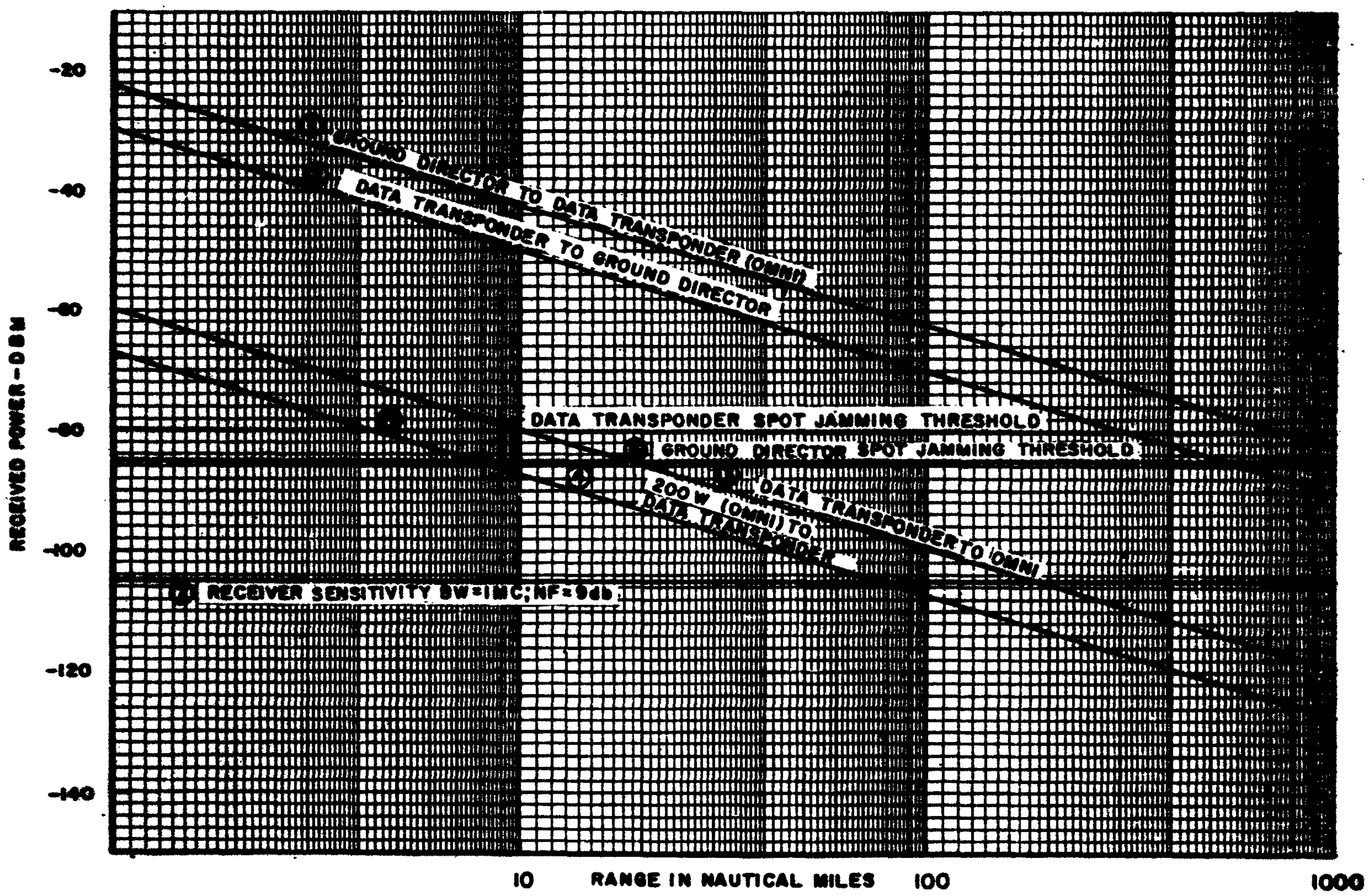


FIGURE 5-7 RECEIVED POWER VERSUS RANGE

Curves 5 and 6 in figure 5-7 show the thresholds above which on-frequency jamming signals must be to cause erratic operation of the ground director and data transponder receivers. Curve 7 in figure 5-7 shows an assumed receiver sensitivity of an ECM (electronic counter measure) receiver being used to detect the MCG radiation. This represents a fairly ideal receiver having a 1 megacycle bandwidth characteristic and a 9 db noise figure and is considered to yield somewhat pessimistic conclusions. In addition, the ECM equipment is considered to be a system with no losses and contains an omnidirectional antenna with a 0 db gain characteristic. The comparison of the assumed receiver sensitivity curve 7 in figure 5-7 and the data transponder curve 3 in figure 5-7 indicate the detection of the drones' data transponder transmitted signal could be accomplished at ranges of 200 nautical miles or less. This range figure is large since atmospheric attenuation losses have not been included.

To evaluate the situation for the ground director, it was assumed that the ECM equipment receiving system is outside of the 2.7-degree beamwidth of the ground director antenna at a point where the gain is down by 30 db and that the range for detection is given by the point where the ground director to the data transponder transmission curve intersects the -75 db abscissa. (See figure 5-7.) This occurs at a range of 420 nautical miles. If a directive antenna system were employed on the drones' data transponder equipment, a detection range of the ground director and data transponder transmitter sources can be calculated. This has been calculated as shown in figures 5-8 and 5-9 for the ground director and the data transponder, respectively.

The data transponder equipments can jam when the on-frequency threshold of the jamming signal exceeds a -80 db in threshold as shown for a spot jamming condition in figure 5-10. Utilization

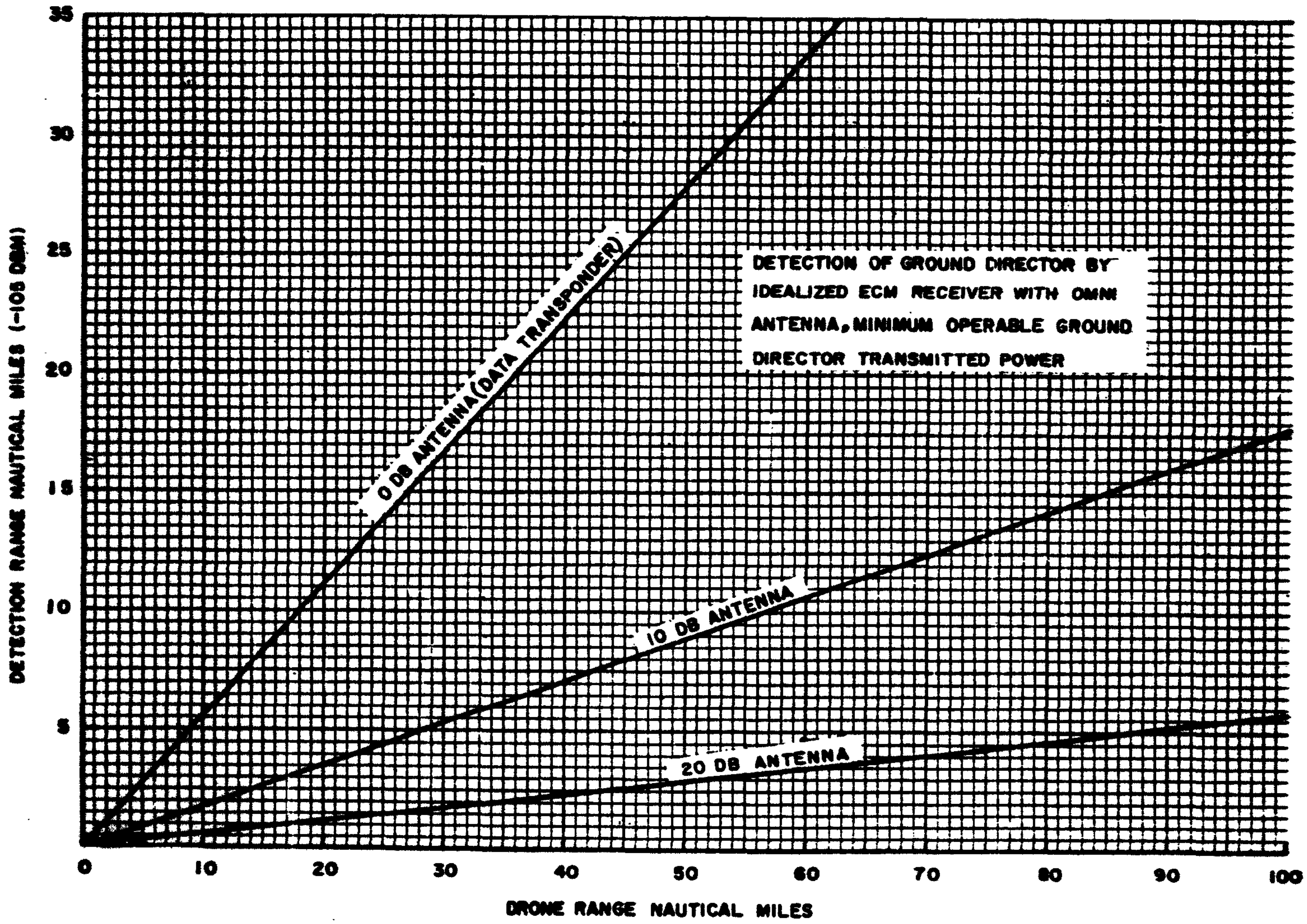


FIGURE 5-8 DETECTION RANGE OF GROUND DIRECTOR TRANSMITTER

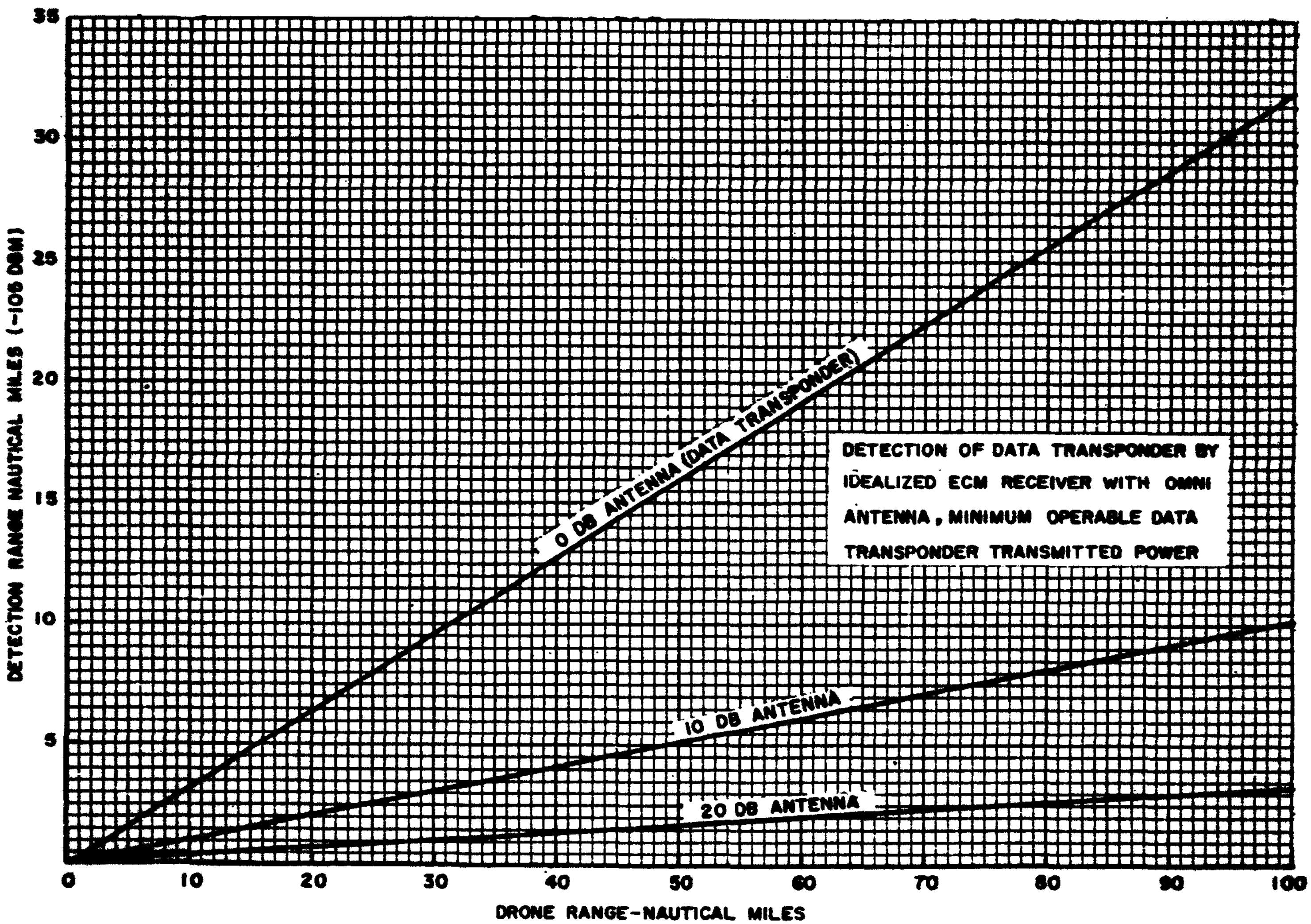


FIGURE 5-9 DETECTION RANGE OF DATA TRANSPONDER TRANSMITTER

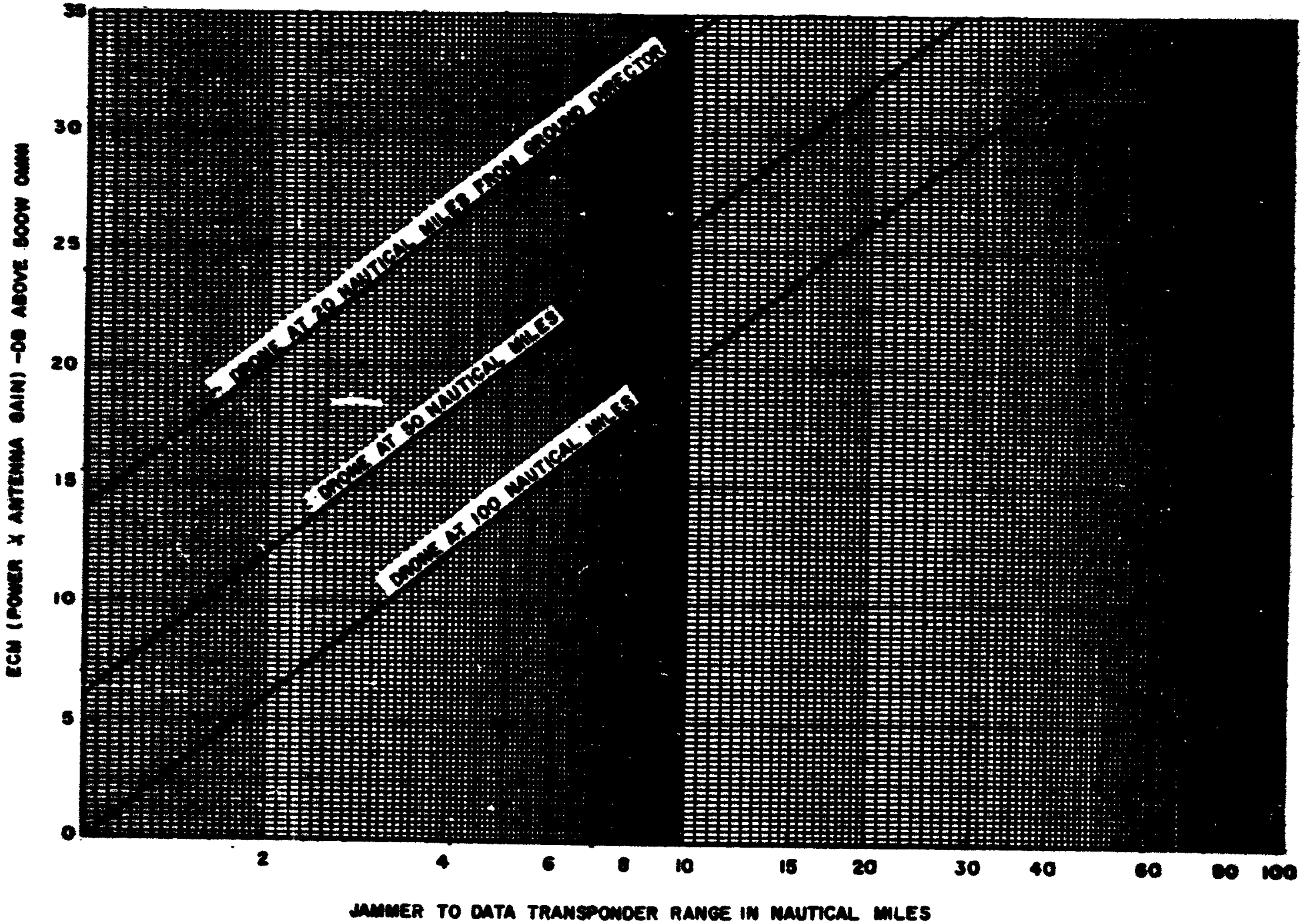


FIGURE 5-10 ECM POWER REQUIRED FOR JAMMING DATA TRANSPONDER

of an AGC System in the data transponder causes the receiver to be further desensitized by the amount equal to the difference between the ground director to data transponder onmicurve curve 1 (figure 5-7) and the data transponder spot jamming threshold curve 5 (figure 5-7). Simply stated, the ground director to data transponder omnicurve becomes a new jamming threshold when AGC is employed. By comparing the ground director to data transponder omnicurve and the 200-watt (omni)-to-data transponder curve (figure 5-7), it is possible to plot a curve of ECM signal power times the antenna gain required for jamming as a function of jamming range. This is presented in figure 5-10 for the drone data transponder at ranges of 20, 50, and 100 nautical miles from the ground director. Thus, for a drone range of 100 nautical miles from the ground director, a jammer located one mile from the drone would require 500 watts to effectively jam the data transponder. A set of curves for the ground director is not presented since the jammer requires even greater power to jam the ground director than the drones' data transponder. This is true assuming the jammer is not in the narrow 2.7-degree antenna beam.

E. EQUIPMENT RELIABILITY

During the process of conducting flight test programs throughout the various ranges such as Holloman Air Force Base and the Eglin Gulf Test Range, figures of merit for reliability of the over-all MCG System have been generated. Reliability and data were obtained from failure reporting during these tests. From these failure reports and from the operating times of each subsystem, mean-time-to-failure values were computed for each subsystem. The over-all reliability was then computed for the system based on the exponential law of reliability and the product rule for a series system. As a result of the reliability program, extensive modifications were made to the data transponder set and to the airborne director relay transponder

set. Reliability figures for operations conducted at the Eglin Gulf Test Range since January 1962 are considered in the following analysis. It should be stated, however, that in the case of the airborne director station the system had not had a complete shakedown flight prior to arrival at the Eglin facility. As a result, the analyses conducted on this particular subsystem will reflect a poor series of results.

The most universally accepted measures of reliability are the values of mean-time-to-failure and the probability of a successful mission of the specified duration. Preliminary studies have indicated that the in-flight failure rates and the ground operation failure rates are not appreciably different; therefore, both types of failures are considered together. The mean-time-to-failure for each subsystem was derived by dividing the total operating time by the number of failures occurring during that time. The total system operating times are established through the use of time-meters installed in each of the subsystems. Table 5-7 lists the total operating time and the number of random failures that occurred for each subsystem. The analysis is based on the characteristic of chance failures which are distributed in time in a random manner described by the exponential law for reliability where

$$R = e^{-t/k}$$

where: R = reliability

t = system operating time in hours during which the reliable operation is sought

k = mean-time-to-failure in hours

In this equation,

$$k = \frac{T}{n}$$

where: T = the number of system hours accumulated during a period of time

n = the number of random failures during this time period.

TABLE 5-7

SUBSYSTEM MEAN-TIME-TO-FAILURE

Subsystem	T Operating Time (hours)	n Random Failures*	k Mean Time To Failure (hours)
Ground Director	548.7	13	42.3
Airborne Director	156	23	6.8
Drone Data Transponder	133	1	133

*Includes all types of failures regardless if they actually affected mission operation or if an indicating lamp burned out.

As an example, calculate the system reliability of a sample mission requiring 2.5 hours of reliable operation from the ground director; 4.0 hours from the airborne director; and 4.0 hours from the data transponder. For the ground director, a reliability of 0.942 is obtained when t = 2.5 hours, n = 13 failures, and T = 548.7 hours. Likewise, at t = 4.0, n = 23 and T = 156, the reliability of the airborne director is 0.555 (as previously stated this figure is extremely low, for new information being obtained from the current mission program anticipates that k = 75 is a more realistic figure and this would result in a reliability of 0.948). The reliability of the data transponder is 0.967 when t = 4.0, n = 1, and T = 133. To find the system reliability with the ground director as prime controller and the airborne director as a series relay station to the data transponder, the product rule applies where the system reliability depends upon the subsystem reliabilities multiplied by one-another taking 0.942, 0.555, and 0.967 as the reliabilities found above, the system reliability becomes 0.505.

New failure records are being recorded, which tend to substitute the 75 hour figure for the airborne director. This will yield a reliability figure of 0.948. Likewise, the actual reliability anticipated for the ground director is in the order of 0.96 which represents a mean-time-to-failure of 100 hours. Using these calculated reliabilities, the system reliability would be 0.883.

For a mission using the airborne director and drone only, a four hour system reliability would be 0.918 (the present data transponder reliability times the anticipated airborne director reliability). In the event that the ground director should fail during the course of an actual relay mission, the airborne director can continue the operation and yield the anticipated reliability as stated. During a high-altitude mission where only the ground director to drone operations are utilized, an actual system reliability factor of 0.910 (actual data transponder reliability times actual ground director reliability) can be obtained for a 2-1/2 hour mission. A system reliability of 0.928 is obtained by multiplying the present reliability of the data transponder and the anticipated reliability of the ground director.

The mathematical analysis of system reliability is based theoretically on the concept that the operation of the system has only two possible outcomes: either success or failure. In practice, this is not generally true. It is possible for a component to fail and not seriously affect the operation of a mission. As an example, during flight, one channel of flight data might fail without causing the mission to abort. However, this is, considered a reported failure and would reflect in the reliability computation of the type made in this report. This type of failure causes a decrease of the over-all calculated reliability but has little bearing on the actual success of the

mission. On this basis, the numbers obtained for the system reliability, presented in this section, are conservative.

F. SYSTEM LOGISTICS

The MCG System has good logistics qualities for limited remote operations. If it is necessary for the MCG System to support a particular mission application at a remote location not requiring the use of the ground director, it is possible to transport the drone vehicle or vehicles and the airborne director (with its personnel) to these remote locations. A complete mission including the low-level mission capability can be conducted with the airborne director and the drone vehicle.

If system requirements call for extended range operations at low altitudes, the GC-130 airborne director is capable of transporting the ground director within its cargo compartment to whatever location is deemed necessary. The drone vehicle, if a service drone type, can be flown by a safety pilot to the designated area of operations. At these remote locations where existing horse power is not available for the ground director, it is necessary that two 30 kw generators be provided to supply the necessary power for the ground director operations.

If it is deemed necessary to conduct missions without the use of the GC-130 airborne director, the ground director, being a mobile element itself, can be transported to any desired location by road or by rail. The ground director can be readied for transport in a matter of hours. To accomplish this transition, it is only necessary to disconnect all externally provided power sources and communications lines which are connected to standard receptacles, stow the tracking antenna in its transporting position at the rear of the van, remove the UHF communications antenna, and secure them internally. For short term limited remote operations, a quantity of spare parts should be

preset frequency. The two-set combination permits a premission choice of 1750 different channels of voice communication. The RF side tone of this equipment is directed to a tape recorder to record and to permit oral monitoring of modulation quality. The tape recorder records all the received transmissions and the amplification of all received and transmitted side tones (voice material) within the ground director. The audio power output is connected to an internal loudspeaker and to an external speaker (outside the van) when such is connected to its external outlets. Headset and microphone outlets are provided at each operator station. The radio set control and a radio signal distribution panel interconnect three operator headsets and microphones, the radio transmitter and receiver, the tape recording heads, and the internal loudspeaker. These communications are of the utmost importance for obtaining mission status and continuity and while conducting the normal checkout procedures for the system.

H. EQUIPMENT FOR OPERATOR COMFORT

Heat dissipation within the ground director is approximately 8 kilowatts from electronic equipment and 1 kilowatt from personnel during operations. To maintain optimum operating conditions for the equipment and operators, an air conditioning unit has been included as accessory equipment. This unit consists of two refrigeration systems, two stages of electric heaters, an air circulation system, and necessary automatic controls. The unit is designed for ventilating, heating, cooling, dehumidifying, and air filtering. Three operating modes of control may be employed when operating the air conditioning equipment. These are ventilating only, ventilating and heating, and ventilating and dehumidifying while cooling. The air conditioning equipment will maintain the ground director at 90°F dry bulb (DB) for external conditions of 125°F (DB) and to 65°F for external conditions

of -40°F. Personal comfort in the airborne director is controllable within the levels of the airborne director cooling and heating equipment.

SECTION VI

GLOSSARY

SECTION VI

GLOSSARY

Since the QB-47/MCG has the triple capability of being operated by either manual, radio, or radar control, words and phrases appear in this analysis which are peculiar to drone aircraft operation. To assist the reader in understanding common drone control terminology the following is provided:

Term	Definition
Airspeed on Pitch	A mode of drone control that allows a reference airspeed to be commanded between high and low limits. Once set, the reference airspeed is maintained by changes in pitch attitude of the drone.
Airspeed on Throttle	A mode of control that allows a reference airspeed to be commanded between high and low limits. Once set, the reference airspeed is maintained by automatic changes in throttle setting.
Altitude Control Engage (ACE)	A command function that establishes a barometric altitude reference. Circuitry within the drone acts to maintain the drone at the reference altitude as long as ACE is in effect.

Term	Definition
AN/APW-20	MSQ-1A - A fixed ground radar command guidance and control with six command functions available.
ARW	UHF radio command guidance equipment.
"Beep" Stick	Commonly used name for the control on the Command Selector which functions as a miniature control stick to initiate turn and pitch commands.
Carrier Failure Sequence	A sequence of programmed commands automatically initiated if all carrier contact is interrupted between the director and drone, which facilitates recovery of the drone.
Circle Turn	A coordinated turn in which the drone is maintained in a continuous circling attitude until commanded otherwise.
Coded Functions	All command transmissions are coded and are termed functions. These commands are routed from a decoder unit of the guidance system receiver through the demultiplexer relay assembly to the drone stabilization and control equipment.
Command Radio	A radio system providing voice communication between drone and director installations. Used primarily for training and orientation purposes.
Cruise Airspeed	A mode of drone control that establishes a preset cruise airspeed as the airspeed reference.

Term	Definition
Director Installation	An installation, either ground based or airborne, of radio, radar, and control equipment from which commands may be transmitted to the drone.
Drone	An airplane used for pilotless flight with the installation of additional equipment.
Drone Stabilization and Control Equipment (DSCE)	Those components of the drone system that perform the functions of stabilization of flight attitude and control of airplane subsystems and auxiliary equipment.
Firing Error Indicator System (FEI)	A system installed in the drone which detects and records the path of an attacking weapon with respect to the drone. Information which is obtained with this system is used in evaluating the performance of the attacking weapon.
Ground Remote Controller, Elevator	A qualified operator to maintain elevation control of the drone from the ground elevator control station during all takeoff and landing operations.
Ground Remote Controller, Rudder	A qualified operator to maintain azimuth control of the drone from the ground rudder control station during all takeoff and landing operations.
Guidance Radio or Radar	The radio or radar system used to transmit commands and receive flight data from the drone.

Term	Definition
Metal Stick Control	A method of drone control used by the safety pilot, primarily for system check-out, training, and orientation purposes. Commands are initiated by the safety pilot from the Metal Stick Controller in the drone. These commands simulate commands from the guidance radio system and are routed to the DSCE.
Navigation Turn	A coordinated turn to establish the drone on a new heading. The turn attitude is maintained only as long as the command is held on.
Nullo Flight	An operational flight of the drone with no human pilot aboard.
Nullo Setup Flight	A flight made with a human pilot aboard, prior to a nullo flight, to determine the necessary adjustment settings required for the nullo flight. The nullo setup flight is made under the conditions that will exist during the nullo flight.
Override Control	A method of control that allows the human pilot to assume manual control of the drone at any time and to stop or alter any remote commands that may be in effect.
Pilot-Director, or Director Pilot	A rated pilot qualified to perform duties as pilot of the director airplane during all phases of remote control operation.

Term	Definition
Pilot-"Beeper"	Commonly called the "Beeper Pilot". A qualified pilot who controls the drone from the director airplane by use of the remote control system.
Pilot, Safety	A qualified pilot in the drone who can take control of the drone at any time. The safety pilot also flies the drone through the metal stick function for training and checkout.
R/S Arm	Range Safety Arm Command functions to prepare to explode vehicle if the vehicle goes beyond the range safety boundaries out of control.
Radar Controller	An operator with sufficient radar training to maintain radar contact with the drone.
Remote Flight	A manned or unmanned flight of the drone in which the drone operational systems are controlled remotely, either through the Metal Stick Control selector within the drone or from a ground or air director station.
Remote Function Switches	Switches which activate the automatic operation of certain drone equipment or operations.
Skid Turn	A turn resulting from rudder and nose wheel movement while the wings are maintained level. Skid turns are possible only during operation with the landing gear extended.

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